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The Middle Pleistocene handaxe site of Shuangshu in the Danjiangkou Reservoir Region, central China

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ABSTRACT

The presence of Acheulean tool types (e.g. handaxes and cleavers) in East Asia has recently attracted considerable attention. They challenge the long lasting concept that the Early Palaeolithic in East Asia is characterized only by Mode 1 technology, and they reflect the diversity and complexity of Palaeolithic culture during hundreds of thousands of years. In this paper, we present a detailed technological analysis of the in situ artifact assemblage at the Shuangshu site (Danjiangkou Reservoir Region, central China), as well as intra- and inter-regional comparisons of some characteristic traits used to test the difference between handaxes in the East and the West. The results show that there are two reduction sequences taking place. One is expressed in the predominant use of quartz in the production the small-to-medium sized artifacts, which is an expedient technology that dominates the whole assemblage, and the other is represented by the predominant use of quartz phyllite and trachyte in the production of Large Cutting Tools (LCTs). The latter displays the technical criteria characteristic of Acheulean technology, although its origins are much debated. In addition, the number of LCTs and total artifacts is generally low for the size of the excavation area, which probably is a result of relatively small population size and the high mobility of hominids. The thickness of handaxes has been shown not to be a reliable variable in demonstrating the difference between the East and the West.

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1. Introduction

One of the prominent characteristics of the Acheulean Industrial Complex is its variability across space and time. This is seen in tool type frequencies (Pope, 2002; Sharon et al., 2011), technological strategies (Clark, 2001; Schick and Clark, 2003; McPherron, 2003; Archer and Braun, 2010), and morphology (Gamble and Marshall, 2001; Lycett, 2008). Moreover, some assemblages (e.g., GnJh 42 and GnJh 50 sites in the Middle Pleistocene Kapthurin Formation of Kenya) actually lack the typical tool types of the Acheulean, such as handaxes and cleavers (Diez-Martín and Eren, 2012; Johnson and McBrearty, 2012). This has led some researchers to recognize the need to form a more balanced focus on exploring a truly holistic version of the Acheulean concept (Tryon and Potts, 2011; Diez-Martín and Eren, 2012; Johnson and McBrearty, 2012). Current emphasis on the small-medium sized débitage component at Acheulean sites exemplifies this more holistic approach, as it helps our understanding of the overall technological innovations and adaptations at these sites (de la Torre and Mora, 2005; Tryon and Potts, 2011; Diez-Martín and Eren, 2012; Johnson and McBrearty, 2012; Gallotti, 2013). However, the study of handaxe-bearing assemblages in China has been constrained by an initial focus on surface collections and the Large Cutting Tools (LCTs) within them (Hou et al., 2000; Norton et al., 2006; Petraglia and Shipton, 2008). This has impeded the reconstruction of complete technological strategies, which are necessary to this more holistic approach.

In this paper, we will present a detailed study of the in situ stone artefact assemblage excavated at the Shuangshu site in the Danjiangkou Reservoir Region (DRR), central China. At the time of the

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construction of the national South-to-North Water Transfer Project, the field team of IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) conducted several investigations along the banks of the Han and Dan Rivers in the DRR (Fig. 1). The survey results show that LCTs are associated with three terraces (T4, T3 and T2) of the Han and Dan Rivers and are estimated to date from the late Early Pleistocene (T4) to the Late Pleistocene (T2) (Zhu, 1955; Shen, 1956; Yan, 1993; Huang and Li, 1995; Chen et al., 1996, 1997; Huang et al., 1996; Li et al., 2009, 2012, in press-a; Kuman et al., in press). Since intensive work began in 2006, more than 20 Palaeolithic sites have been excavated (Pei et al., 2008; Zhou et al., 2009; Niu et al., 2012, 2014; Fang et al., 2012; Li et al., 2013; Chen et al., 2014). Of all the excavated sites, Shuangshu contains the largest number of LCTs on the third terrace (T3) of the DRR, and it is one of the few sites where systematic dating work has taken place. The purpose of this study is to have a closer look into the complete technological strategy of handaxe makers in the DRR. Furthermore, we discuss its implications for understanding the handaxe phenomenon in China within a comparative approach.

2. Geological setting and palaeoenvironment

The Shuangshu site is located in the Junxian Basin in the upper valley of the Han River (E111°07′19″, N32°40′24″). Some parts of the basin have been submerged because of the construction of the Danjiangkou Reservoir (Fig. 1). Geologically, the Shuangshu site is located in the southern Qinling tectonic belt. Due to the Yanshan movement in the Mesozoic era, northwest-southeast intermontane fault basins formed (e.g. Junxian Basin, Yunxian Basin in Fig. 1)

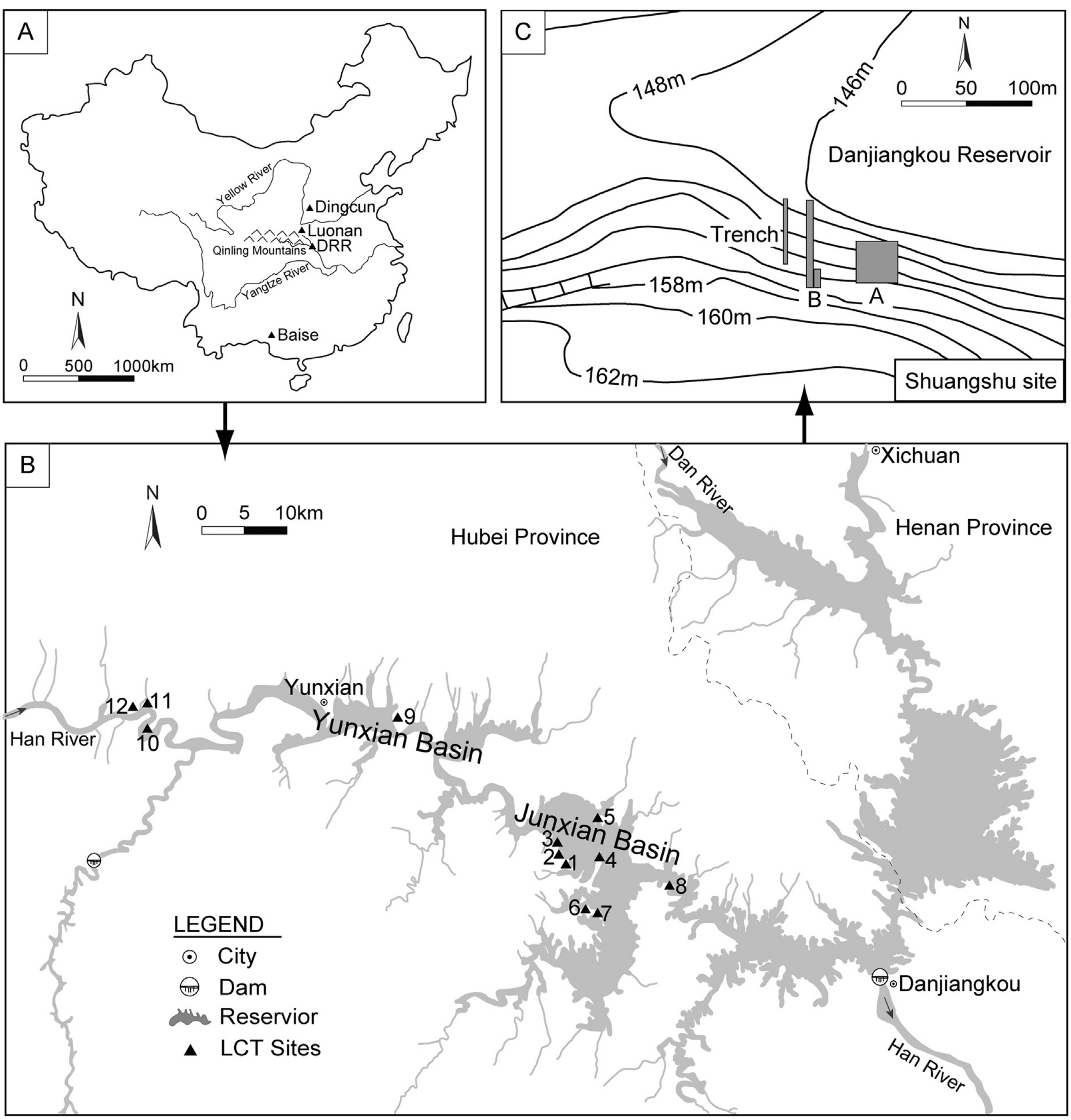

Fig. 1. Handaxe regions of China. A) geographic location of the main handaxe-bearing regions. B) the Danjiangkou Reservoir Region (DRR) with the Palaeolithic sites mentioned in this paper: 1. Shuangshu; 2. Shuiniuwa; 3. Beitaishanmiao II; 4. Beitaishanmiao; 5. Guochachang II; 6. Datubaozi; 7. Waibiangou; 8. Pengjiahe; 9. Liuwan I; 10. Houfang; 11. Dishuiyan; 12. Xuetangliangzi (or Yunxian hominid site). C) the Shuangshu site excavation areas and trench noted in the text.

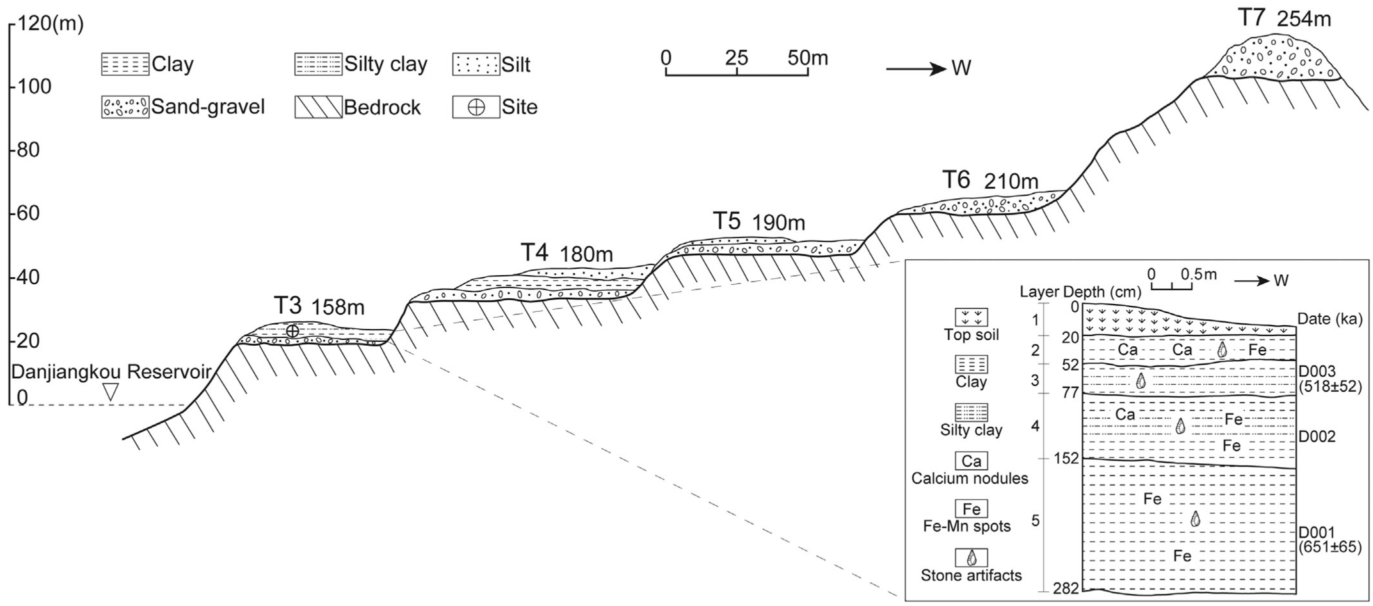

Fig. 2. The fluvial terrace sequence at Shuangshu, with stratigraphic profile (bottom right) for terrace three recorded in the Trench.

along the early deep fracture in this area (Zhang et al., 1988; Xue et al., 1996). The area today is dominated by the canyon geomorphology of the upper valley of the Han River as it flows through the Qinling Mountains, with steep slopes, turbulent water, and undeveloped terraces. However, when the Han River flowed through the basins, the valley was broad and developed several river terraces (Zhu, 1955; Shen, 1956).

The field survey around the site indicates that there are seven terraces in this area. Of these, terraces one and two are the youngest and are submerged, while the others terraces are currently exposed. The Shuangshu site is located on the third terrace of the south bank of the Han River, and is composed of two distinct stratigraphic units: the upper clay layer and the lower cobble layer. It is an extensively developed and well preserved terrace, with most farmlands and villages in the region located on this terrace. The elevation of terrace three is about 158 m and the terrace floor is about 25 m higher than the water surface of the Danjiangkou Reservoir (Fig. 2).

From the palaeoenvironmental perspective, the Qinling Mountains form the boundary between North and South China and separate the temperate and subtropical zones. This boundary area currently receives ca 800 mm of annual precipitation (Atlas of China, 2007). The Shuangshu site is located in the extreme southeastern part of the Qinling Mountains, and analyses of the fossils from the late Early Pleistocene to the Late Pleistocene levels indicate that the fauna were typical of southern China (Ailuropoda-Stegodon fauna) at the time (Qiu et al., 1982; Li and Feng, 2001; Wu et al., 2008, 2009). Some northern Chinese species (*Equus ferus przewalskii*, *Crocuta crocuta ultima*, *Ursus arctos*) do appear in the Late Pleistocene, although their proportion is lower than in the contemporary northern China fauna (Huang et al., 1987; Wang,

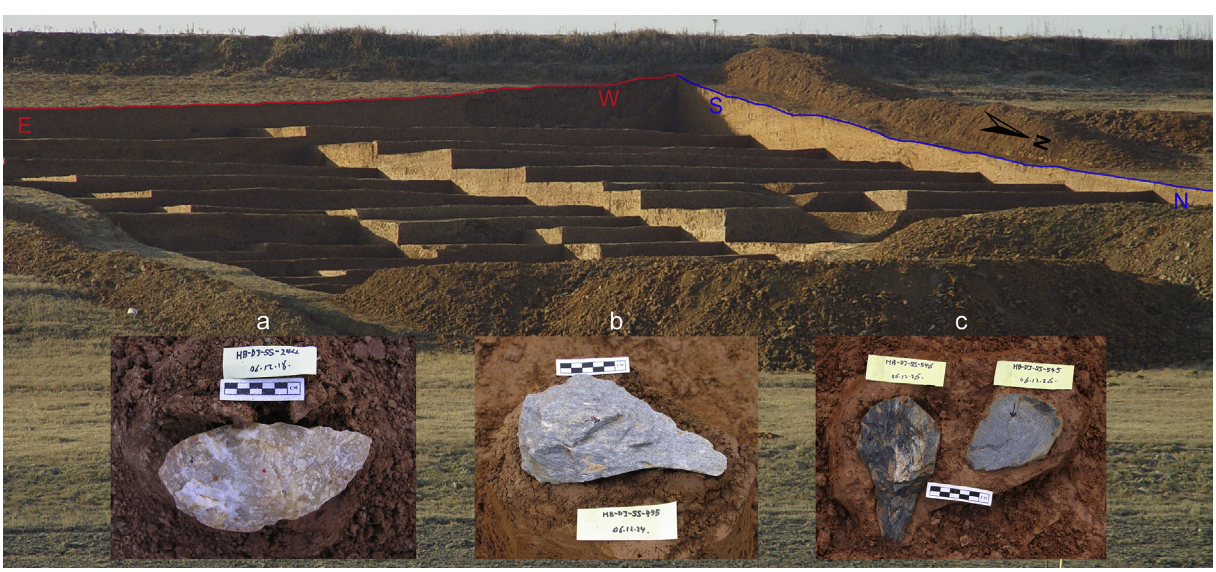

Fig. 3. Area A of the Shuangshu site and the in situ artifacts exposed during the excavation: a) handaxe on quartz, SS-244; b) handaxe on trachyte, SS-495; c) two handaxes made on quartz phyllite, SS-546 (left) and SS-545 (right). The red line shows the East-West direction and the blue line shows the North-South direction. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

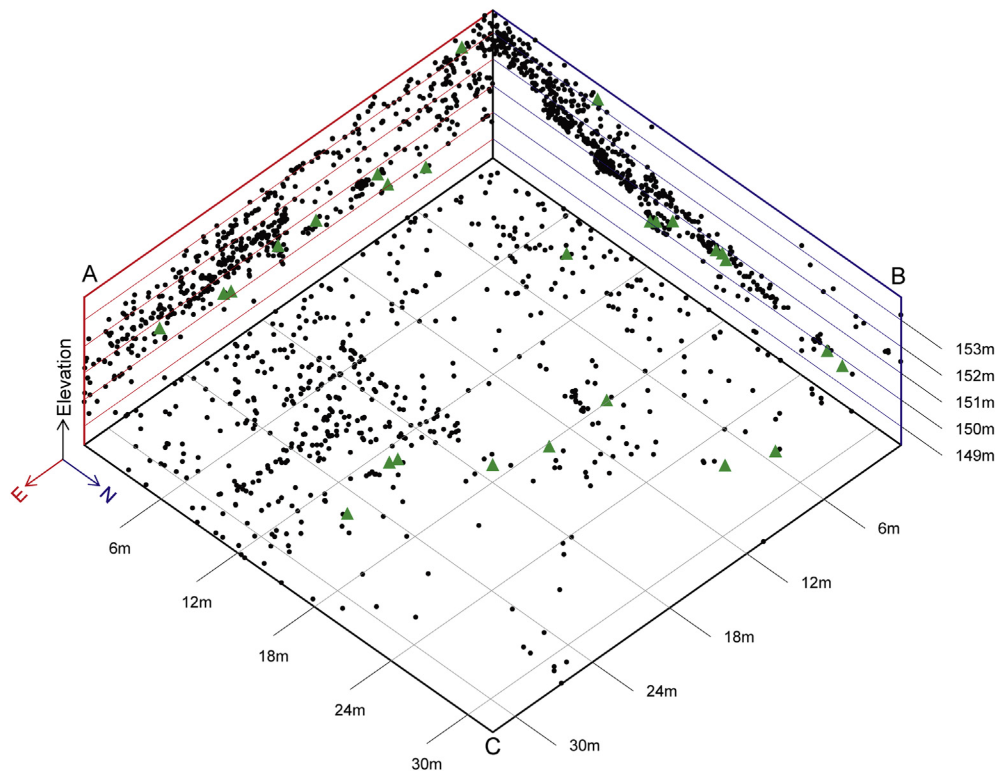

Fig. 4. The plan and cross-section distributions of lithics excavated in Area A. The red lines (A) show the East-West cross-section; the blue lines (B) show the North-South cross-section; the gray lines (C) show the lithics in plan view. Green triangles represent LCTs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1988; Wu et al., 2006, 2007). In the Pleistocene, this area experienced a relatively stable subtropical environment, with abundant animal and plant resources providing good subsistence opportunities for the survival of early humans.

3. Site stratigraphy and chronology

3.1. Stratigraphy

The Shuangshu site was discovered in 2004, and excavations were conducted from November 2006 to January 2007 by IVPP. The total excavation area was 1435 m^2. There were three excavation areas (see right top map in Fig. 1): a trench 50 m long and 1.5 m wide (75 m^2); the Area A excavation 1024 m^2 in size (see Fig. 3); and the Area B excavation 336 m^2 large. In total, 706 lithics were excavated from the Shuangshu site: $N = 21$ from the trench, including four handaxes; $N = 592$ from Area A, including six handaxes, two picks and one atypical cleaver; and $N = 93$ from Area B. The average density was 0.49 specimen/m^2 within all three areas. The plan and sectional distributions of lithics excavated from the Area A are shown in Fig. 4.

The stratigraphy of the site was divided into five layers, as follows (from the upper to the lower, see right bottom map in Fig. 2):

Layer 1: Brown clay, top soil (~20 cm);
Layer 2: Reddish-brown clay, containing stone artifacts, black Fe-Mn spots, and more calcium nodules (~32 cm);
Layer 3: Reddish-yellow clay, with silt, containing stone artifacts (~25 cm);
Layer 4: Reddish-brown clay, with silt, friable, containing stone artifacts, black Fe-Mn spots and fewer calcium nodules (~75 cm);
Layer 5: Reddish-brown clay, strong cohesive, stiff, containing stone artifacts and more black Fe-Mn spots (~130 cm) (the bottom is not obtained).

The cultural finds at Shuangshu are distributed throughout most levels in the clay layers (Fig. 2), which correspond to low energy deposition.

3.2. Chronology

Currently, the most extensive dating work has been conducted on the fourth terrace (T4) of the Han River, because of the discovery of two hominid crania (evolved *Homo erectus* or archaic *Homo sapiens*) at the Xuetangliangzi site (Fig. 1). The base of this terrace is about 180 m above sea level, which lies ca. 45 m above the current water level in the Danjiangkou Reservoir. Relative dating based on paleomagnetism, faunal chronology, and comparison with the loess-palaeosol sequence from the Luochuan profile on the Loess Plateau all indicate that Xuetangliangzi site falls in MIS19-MIS20 (814–761 kya) (Yan, 1993; Huang and Li, 1995; Chen et al., 1996, 1997; Li and Feng, 2001; De Lumley and Li, 2008; Guo et al., 2013).

In contrast to this higher and older terrace (T4) in the DRR, terraces one and two at the site are now submerged. However, a survey in the 1950s, prior to construction of the Danjiangkou Reservoir, indicates that terrace one is no more than 10 m higher than the riverbed and is composed of yellow sandy silt (Zhu, 1955; Shen, 1956). Recently in western Yunxian County, OSL dating of the earliest loess on terrace one indicates that it was deposited from 18.0 kya (Gu et al., 2012). Terrace two in the DRR was 10–15 m above the riverbed before construction of the reservoir, with the base of this terrace at 140 m above sea level, characterized by yellow clayey silt (Zhu, 1955; Shen, 1956). The age of terrace two is

estimated to the middle or late Pleistocene based on its sediments and on height compared with other terraces. Currently, the only published date for terrace two is from the Dishuiyan site (800 m east of Xuetangliangzi), with a result of ca. 100–50 kya using the OSL and TT-OSL methods (Liu and Feng, 2014). The Shuangshu site of terrace three in the DRR sequence is considered on sedimentological grounds to be younger than the terrace four Xuetangliangzi site, but older than the second terrace sites in the DRR. The deposits of the Shuangshu site are strongly weathered red clay, which formed in a humid period, and these acid sediments did not preserve fossils. Both the calcium carbonate nodules and the Fe-Mn spots in the red clay (see Fig. 2) are good indicators of intense weathering and pedogenesis process at the time. The study of red clay development in Pleistocene South China has revealed that the Qinling Moutains form the northern boundary of the red clay deposits formed during the most humid period (Zhao and Yang, 1995; Yang et al., 1996; Yuan et al., 2008). The Shuangshu site is located in this boundary area of the red clay, which means the formation of red clay in this region should fall within the most humid period of the Pleistocene (Yuan et al., 2008; Pei et al., 2008; Zhou et al., 2009; Niu et al., 2012; Li et al., 2013). The study of the loess-palaeosol sequence in China is well established and shows that palaeosol S5–S4 (equal to MIS15-11, 621–374 kya) represents a most intense humid stage in the Pleistocene, best suited for the formation of the red soil in the DRR region (Zhao and Yang, 1995; Yang et al., 1996; Huang et al., 1999; Zhao et al., 2004; Yin and Guo, 2006; Yuan et al., 2008).

The Electron Spin Resonance (ESR) dating method is now commonly used to obtain accurate ages for Pleistocene fluvial sediments, especially using the confirmed quartz titanium (Ti)-center as a reliable ESR signal for dating (Beerten et al., 2006; Beerten and Stesmans, 2006, 2007; Bahain et al., 2007; Tissoux et al., 2007; Rink et al., 2007; Liu et al., 2009, 2010, 2011). For example, applying the ESR dating method to the sandy layer (layer I-26a) of the Ubeidiya Early Acheulean site in the Jordan Valley of Israel, it was shown that this method is suitable and reliable for dating older deposits that exceed the dating range of OSL or TL (<0.5 Ma). The dating results using this method are consistent with the relative palaeomagnetic and faunal dates for Ubeidiya (1.0–1.4 Ma) (Rink et al., 2007). The systematic application of the ESR optical dating method has also been applied to fluvial deposits in the Somme Valley of France, where the Acheulean was first defined, revealing that the first human settlement here began in MIS 16/15 (ca. 0.6 Ma) (Bahain et al., 2007; Voinchet et al., 2010). In China, this method was recently used to date archaeological sites in the Nihewan Basin. The reliability of ESR optical dating of quartz was first examined for reference sample collected near the Brunhes/Matuyama (B/M) boundary at the Donggutuo site, where the presence of the B/M boundary as well as the Jaramillo subchron in the silty sequence of this site have been confirmed (Wang et al., 2005). ESR dating on this sample yielded an age of 750 ± 88 kya, which suggested that the method is reliable for estimating the age of lacustrine and fluvial sediments at least until this age (Liu et al., 2010). This dating method was then applied to the Majuangou, Banshan and Dongpo sites, where the dates are consistent with the previous magnetostratigraphic and geomorphological estimations (Liu et al., 2010, 2013, 2014).

Given these successes with ESR dating, we decided to apply the method to fluvial deposits at Shuangshu. ESR dating samples were collected from layers 5, 4 and 3 of the site and were numbered D001, D002 and D003 from the lower to upper layers. The lithology of the samples was clay. The State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, analyzed the samples. The paleodose of D001 was 2499 ± 250, and the annual dose was 3.841. Therefore, the age of D001 was 651 ± 65 ka. The signature of D002 was poor, thus the age was undeterminable. The paleodose of D003 was 1792 ± 180, and the annual dose was 3.457. This indicates that the age of D003 sample was 518 ± 52 ka (Table 1). From the ESR dating, the age of the Shuangshu site appears to belong to the first half of the Middle Pleistocene.

Table 1
ESR dating of terrace three clay samples collected from the profile in Area A at Shuangshu.

Sample number	Stratigraphic unit	Lithology	Paleo-dose (Gy)	Annual dose (Gy/ka)	Age (ka)
D001	Layer 5	Clay	2499 ± 250	3.841	651 ± 65
D002	Layer 4	Clay	–	3.255	–
D003	Layer 3	Clay	1792 ± 180	3.457	518 ± 52

A detailed magnetostratigraphic analysis was also carried out on the profile of the Shuangshu site. The paleomagnetic sample section began at the top of terrace three and sampled down the western wall of the excavation in Area A to near the surface of the water. To ensure that we obtained fresh and original outcrops of samples, ~50 cm of the wall was first cut back. Samples were then collected at 10 cm intervals, resulting in a total of 86 oriented block samples. Then, two parallel samples with a volume of $2 \times 2 \times 2$ cm^3 were cut out of each block in the laboratory for rock magnetic and magnetostratigraphic studies. The analyses were conducted at the Paleomagnetism and Geochronology Laboratory, Institute of Geology and Geophysics, Chinese Academy of Sciences. The samples were heated to maximum 690 °C using MMTD80 Thermal Demagnetizer, with 25°–50 °C temperature increments below 600 °C and 10°–20 °C temperature increments above 600 °C. Remanence measurements were made using a 2G-760 cryogenic magnetometer at a magnetically shielded space (<300 nT). The high-stability natural remanent magnetization was separated above ca. 300 °C and adopted as characteristic remanent magnetization. Principal component analysis of the magnetic components (Jelinek, 1978) showed that all 86 samples provided reliable characteristics of remnant magnetization. Except for the sample from 3.4 m deep, all samples were of normal polarity (Fig. 5). Considering the ESR dating results and combined with the international polarity time scale (Cande and Kent, 1995), it is likely that the site was formed in the "Brunhes normal chron" which means the site was not formed earlier than 0.78 Ma.

The dating results from ESR and the paleomagnetism measurements therefore indicate that the Shuangshu site likely belongs to an early to middle stage of the Middle Pleistocene. This is consistent with the former geomorphological and sedimentary observations. Nevertheless, dating work on the third terrace sites of DRR is still very limited, and the application of additional dating methods on more samples is a top priority for future research.

4. Lithic assemblage

4.1. Assemblage component

Flakes (complete and incomplete flakes) comprise a dominant proportion ($n = 269$), or 38.1% of the whole assemblage (see Fig. 6 for artifacts number of each category). Chunks and debris (<25 mm) were the second and third largest proportions ($n = 149$ and $n = 116$ respectively), or 21.2% and 16.4% respectively. There were 67 cores in total, or 9.5% of the assemblage. There were 55 retouched pieces, or 7.8% of the assemblage. LCTs totaled 13 pieces, or 1.9% of the assemblage. Among them, 10 were handaxes, 2 were picks and 1 was an atypical cleaver. Five hammerstones and two

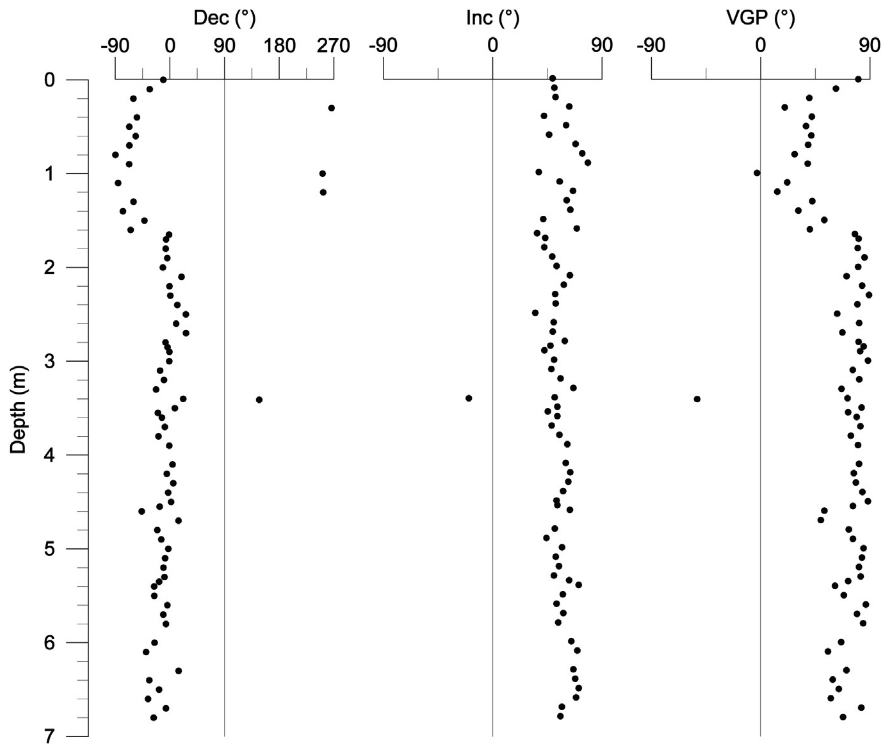

Fig. 5. Magnetic readings of the Shuangshu site: declination (Dec); inclination (Inc); virtual geomagnetic pole (VGP) latitude. The samples were collected from the N–S wall in the Area A excavation.

anvils were also unearthed. In addition, there were 30 unmodified pieces called manuports. With regard to the size, flakes, chunks, debris, cores and the retouched pieces were predominately small to medium size (0–10 cm), while LCTs were of large size (>10 cm) (Fig. 6). By putting different types of artifacts together, we can see that 47.6% of lithic length is < 40 mm and 71.0% of lithic length is < 60 mm (Fig. 7). In general, the size profile of the assemblage indicates a relatively stable taphonomic environment when deposited on the clay surface. However, there could have been moderate sheet wash along the ancient natural slope that winnowed some of the smallest artifacts from the site, as only 10.6% of lithic length is < 20 mm (Fig. 7).

4.2. Raw materials

Raw materials investigation at the site shows that the lower cobble layer on the third terrace provided a locally available source of raw materials. The thickness of the cobble layer is approximately 6 m. Cobbles are dominated by sub-rounded shapes, along with rounded and sub-angular shapes. The sub-angular cobbles can provide the natural facets which may be used as striking platforms in the initial stage of knapping. The size of cobbles is concentrated in 2–20 cm range, with the maximum size up to 30 cm. Rock lithology is dominated by quartz, quartz phyllite and trachyte, with a smaller number of sandstone, quartzite and other igneous rocks. In the Shuangshu site, raw materials were mainly quartz ($n = 587$; 83.1%), quartz phyllite ($n = 88$; 12.5%), and trachyte ($n = 26$; 3.7%). Quartzite and sandstone were only occasionally used and constitute 0.4% and 0.3% of the assemblage respectively (Table 2). It is obvious that the availability of local raw materials plays an important role in the tool makers' selectivity.

The proportion of various raw materials used in the manufacture of different sized artifacts is clearly defined (Table 2). Quartz was mainly employed in the production of small to medium sized artifacts. It accounted for 83.8% in the cores, 86.6% in the flakes, 81.2% in the chunks, 100% in the debris and 87.3% in the retouched pieces. In contrast, of the 13 LCTs, only one is made of quartz, eight of quartz phyllite and four of trachyte. Fig. 8 shows our investigation of raw materials at a quarry sorting factory on the bank of the Han River. The three enlarged images clearly demonstrate the size variation of cobbles from small to large, which is consistent with previous observations of the third terrace cobble layer. The dark gray color generally represents quartz phyllites, the dark green color indicates trachytes, while the light white and brown colors mainly indicate quartz, quartzites and sandstones. It is notable that different colors of rocks repeatedly appeared in all three images, which indicates there is no lithological selection by size. However, considering the selection of raw materials in making different types of artefacts, it is apparent that the Shuangshu toolmakers had a skillful understanding of the quality of different raw materials. Regarding small to medium sized débitage, the makers may have aimed to acquire sharp-edged flakes which can be used directly, as experimental and use-wear studies have revealed that flakes may not simply represent debitage or “waste” but rather a central component of the toolkit (Toth, 1982, 1985; Sussman, 1985, 1988; Schick and Toth, 2006). To this end, the quality of the local quartz, which can provide sharp, and can fracture easily, could be more favorable in this requirement. On the other hand, although quartz phyllite and trachyte cobbles are also abundant in the river bank, they were mainly used to make LCTs. Both of these raw materials are not homogenous and show internal fractures (see the experimental flaking in Fig. 12: a1, a2, a3 and b1, b2, b3). Nevertheless, they were still better for some tasks than the brittle quartz, which was less predictable for knapping large flakes or for directly making large-sized tools on cobbles. However, if suitable quartz was available, LCT makers did on occasion use it (see Fig. 12: 1).

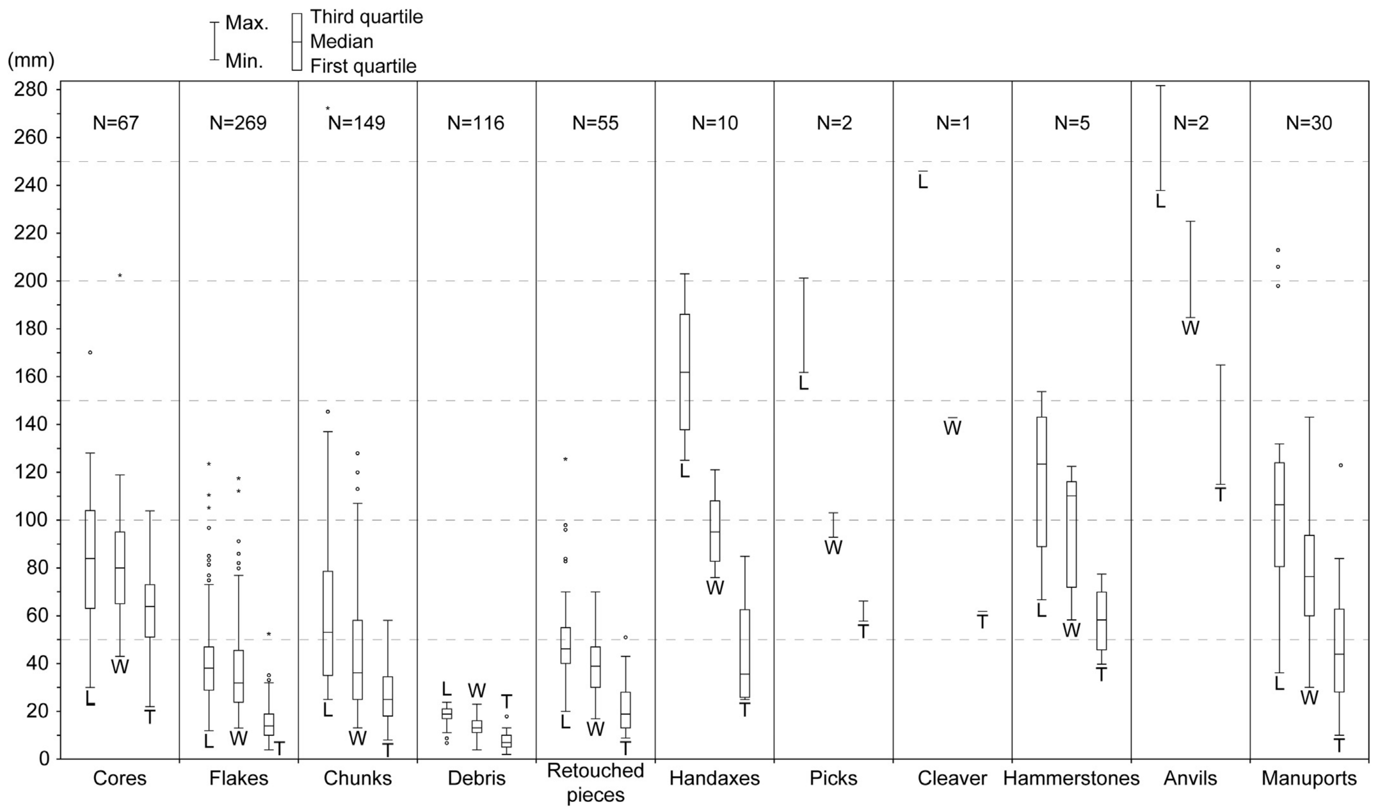

Fig. 6. Box plot of the length (L), width (W) and thickness (T) for different types of artifacts.

4.3. Small-medium sized débitage

4.3.1. Cores

In total, 67 cores were excavated from the site, 57 of them made of quartz (85.1%). The size of the cores was predominately small to medium, with average dimensions of 82.6L × 81.8 W × 61.7 T (mm) and an average weight of 591.7 g. The dominant flaking technique was free hand percussion, with only one bipolar core identified. Among the 66 free hand percussion cores, 46 (69.7%) are chopper (or chopper-like) cores, with 36 flaked on the cortical surface or on simply flaked surfaces (Fig. 9: 1–2), and with ten flaked on two unadjacent platforms. The other 20 (30.3%) cores show bifacial alternating flaking, in which the removals were struck on two adjacent surfaces with negative scars used alternatively as a striking platform to flake the other plane (Fig. 9: 3–4). A total of 98 platforms are present on the 67 cores. Among them, 40 are on natural cobble surfaces and 58 are on flaked surfaces, which supplied a flatter surface for flaking without the need of preparation (Fig. 9: 1–2). The high proportion of natural surfaces shows, however, that hominids tended to select cobbles that had suitable flaking surfaces from the beginning. This is demonstrated in Fig. 8, which shows that some raw materials are sub-angular in shape. The natural facets on these cobbles provide advantageous angles to facilitate the initiation of removals. Flake scars on the cores were low, with an average number of 3.8 scars per core, which reflects the abundance of raw material. Twenty-one cores had one to two flake scars, which makes them casual cores (Fig. 10). This technological data shows that the exploitation of cores was low and generally random.

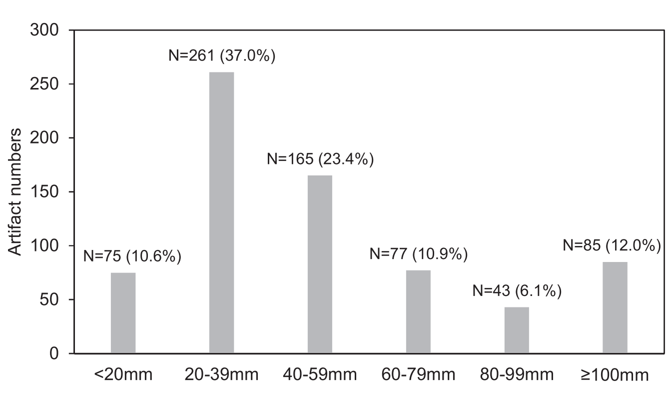

Fig. 7. Size profile for the Shuangshu assemblage.

4.3.2. Flakes

Of the 269 flakes recovered from the site, 232 are made of quartz (86.2%) (Fig. 9: 6–9). The size of flakes is generally small, with average dimensions of 40.7L × 36.4 W × 15.3 (mm) and an average weight of 31.0 g. The dominant flaking technique is free hand percussion, with only 17 bipolar flakes identified. Among the free hand percussion flakes ($n = 252$), 126 (50.0%) have cortical platforms, 124 (49.2%) have plain platforms, and only two (0.8%) have simple faceted platforms. With regards to the dorsal surface of the flakes, six (2.4%) are totally cortical, 150 (59.5%) have flake scars but lack cortex, and 96 (38.1%) show a mix of scars and cortex. A classification of flakes using Toth's (1985) method is shown in Fig. 11. Accordingly, about half of the flakes were likely in the advanced stages of flaking (type V, 20.6%; type VI, 29.0%), which is inconsistent with the low degree of flaking on the cores. However, the local quartz has natural fractures, causing it to break into chunks during the knapping process. If these chunks were used as cores, then flakes from advanced stages of production would be produced. This idea is supported by the numerous chunks from the site which will

Table 2
Tool types and raw materials.

Type	Quartz	Quartz phyllite	Trachyte	Quartzite	Sandstone	Total	%
Cores	57	5	4	1		67	9.5
Flakes	232	26	11			269	38.1
Chunks	121	23	4	1		149	21.2
Debris	116					116	16.4
Retouched pieces	48	7		1		55	7.8
Handaxes	1	5	4			10	1.4
Picks		2				2	0.3
Cleaver		1				1	0.1
Hammerstones	4				1	5	0.7
Anvils		1			1	2	0.3
Manuports	8	19	3			30	4.2
Total	587	88	26	3	2	706	100
%	83.1	12.5	3.7	0.4	0.3	100	

be described below. The total flake number ($n = 269$) is close to the flake scar number on all the cores ($n = 253$) confirming our technological observation of the cores and showing that extensive transportation of cores or flakes out of the site was not likely. One rejuvenation flake is present (Fig. 9: 12), showing the removal of the distal end of a handaxe (i.e., a tranchet flake that removes the convergent end of the piece).

4.3.3. Chunks

One hundred forty-nine chunks were found on site with 121 being made of quartz. The average size of chunks is small to medium, with average dimensions of 61.9L × 44.1 W × 29.2 T (mm) and an average weight of 178.9 g. These numerous quartz chunks reveal the easily-broken nature of the quartz. On average, cortex covered 65.3% of the chunks, showing that most were in the preliminary stages of production.

4.3.4. Debris

There were 116 pieces of debris (<25 mm) from the site, all of them made of quartz. Experimental results have shown that, if the proportion of small flaking debris (<20 mm) is 60–75%, the site should be regarded as in primary context without disturbance (Schick, 1986, 1997). Quartz debris at the Shuangshu site, however, only comprises 19.8% ($n = 116$) of the total quartz artifacts ($n = 587$), indicating the site was modified to a certain degree during the formation of the site.

4.3.5. Retouched pieces

In total, 55 retouched pieces were unearthed from the site, 48 made of quartz (Fig. 9: 10–11). The size of retouched pieces is small to medium, with average dimensions of 51.1L × 39.8 W × 21.3 T (mm) and an average weight of 53.0 g. On average, cortex covers 22.5% of each piece. Forty-eight pieces are made on small to medium flake blanks, five on chunks, and two on cores. The retouch is simple and the intensity is low. Single retouched edges dominate the assemblage. Among them, 24 are straight edges, 16 are convex edges and eight are concave, although four have double edges and three have edges retouched along the whole circumference of the flake. Retouched pieces form part of the small-medium artifacts' reduction sequence in terms of their raw materials, size and blanks. Hominids procured quartz from the local cobble layers and transported them into the site, then conducted simple flaking and retouch. Quartz phyllite and quartzite were also used in this sequence, but in a lower frequency (see Table 2).

Fig. 8. Lithic raw materials collected from gravels are sorted by size at a quarry on the bank of the Han River. The three enlarged images clearly demonstrate the size variation of cobbles from small to large. See details in the text.

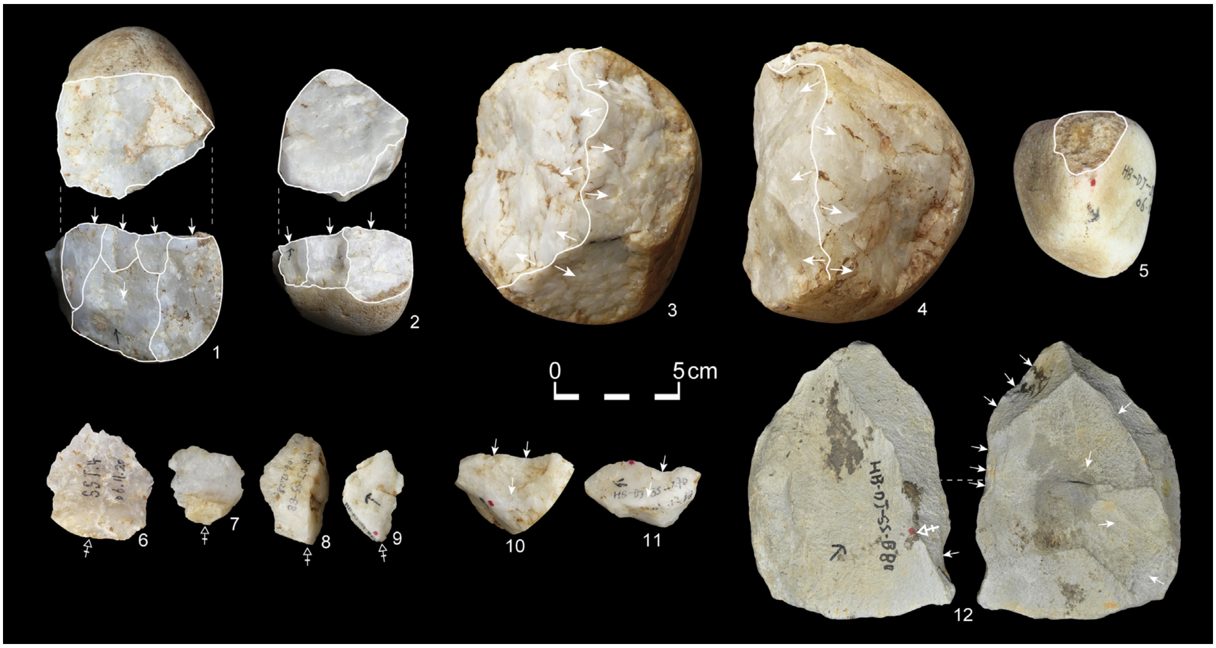

Fig. 9. Artifacts from Shuangshu: (1–2) SS-220, SS-392B: cores with simply flaked surface; (3–4) SS-376, SS-208: cores with bifacial alternating flaking; (5) SS-285, hammerstone; (6–9) SS-T4, SS-T19, SS-B8, SS-B64: flakes; (10–11) SS-119, SS-270: retouched pieces; (12) SS-B80, rejuvenation flake. White arrows show direction of the flake scars, and the hollow triangles indicate the strike direction (Black arrows record cardinal directions of excavated pieces).

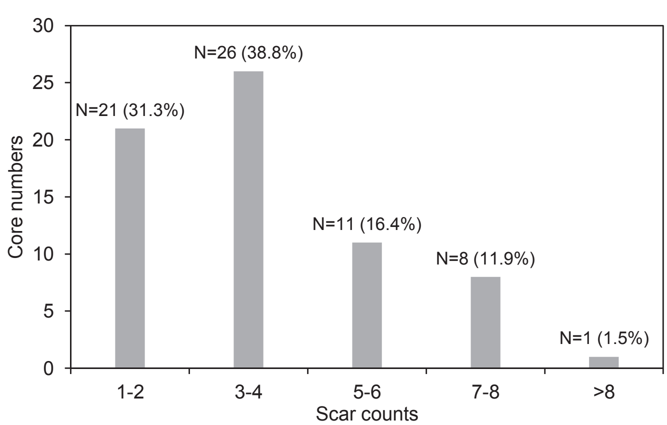

Fig. 10. The scar counts on cores.

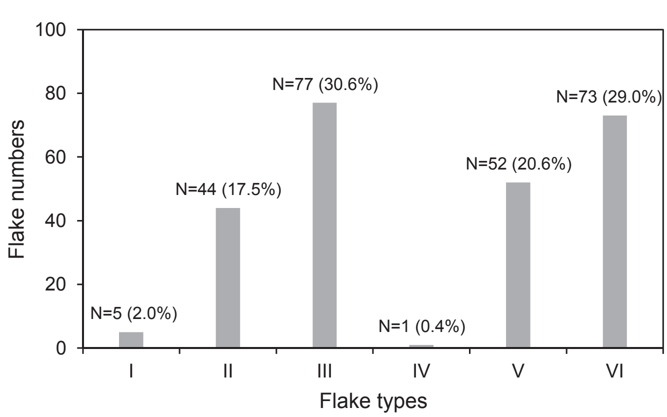

Fig. 11. The classification of flakes using Toth's (1985) method.

4.4. Large Cutting Tools production

Altogether, 13 LCTs were excavated. Ten of them are handaxes, two are picks and one is an atypical cleaver as it has a wide unretouched bit. Because of the importance of the in situ findings of LCTs in the Shuangshu site, individual information is provided for these 13 artifacts, together with the surface collected LCTs from Shuangshu for the comparative purpose in the section below (Table 3). The average dimensions of handaxes are 162.5L × 96.5 W × 44.0 T (mm) and the average weight is 749.6 g. Cortex averages 34.0% per piece. The average dimensions of picks are 181.5L × 98.0 W × 62.0 T (mm) and the average weight is 1165.0 g. The cortex average is 45.0% per piece. The dimension of the single cleaver is 246.0L × 143.0 W × 62.0 T (mm) and its weight is 2088.0 g. Cortex covers 30.0% of the tool surface. Two indices, Length/Breadth (elongation) and Thickness/Breadth (refinement) are thought to be useful variables for characterizing and discriminating LCT assemblages (Wynn and Tierson, 1990; White, 1998; Shipton and Petraglia, 2010). The average L/B (elongation) of handaxes and picks is 1.69 and 1.85 respectively, and the average for T/B (refinement) is 0.45 for handaxes and 0.63 for picks.

Five handaxes are made of quartz phyllite, four of trachyte and one is made of quartz. The two picks and single cleaver are both made of quartz phyllite. These facts reveal that the raw materials being exploited for the production of LCTs were different to the raw materials used to make small to medium sized artifacts.

Four handaxes are made on cobbles (Fig. 12: 1–4; Fig. 14: 1, 3, 5), five on large flakes (>10 cm) (Fig. 13: 1–4; Fig. 14: 2, 4, 6–8, 10), and one is indeterminate because of the intense weathering of this specimen. Of the two picks, one is made on a flake blank and the other on a split cobble blank (Fig. 14: 9). The solitary cleaver is made on a flake blank (Fig. 14: 10). The striking platforms of flake blanks are dominated by cortex, with an average of 40% of the dorsal face being cortex. These features show that most flake blanks are likely the primary flake, also called the cobble opening flake. This same situation occurs at the Ternifine site in North

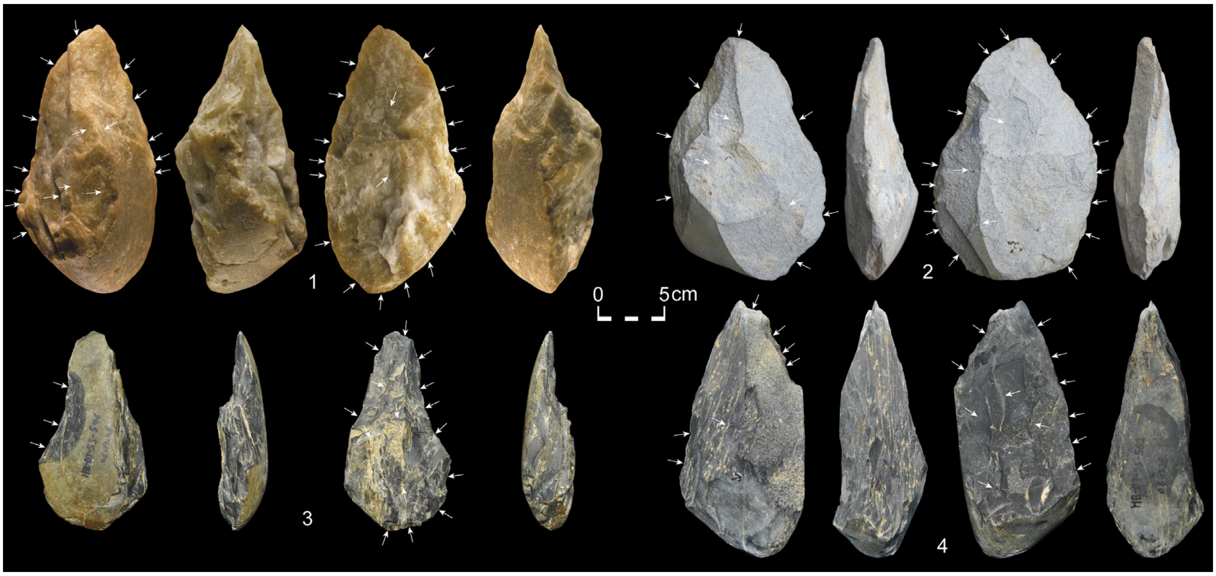

Fig. 12. Handaxes made on cobble blanks: (1) SS-244, quartz handaxe; (2) SS-T21, trachyte handaxe; (3) SS-546, quartz phyllite handaxe; (4) SS-562, quartz phyllite handaxe.

Africa, and the El Sartalejo site in Spain (Sharon, 2007). These kinds of blanks are typical and are regarded as an adaptation to the local raw materials. Comparisons were made with experimentally flaked stones (see Fig. 13: a1-3, b1-3 for the bipolar technique; Fig. 13: c1-3 for the throwing technique), which suggest the archaeological assemblages contains one bipolar flake (Fig. 13: 3; Fig. 14: 7) and one throwing flake (a cobble thrown against an anvil stone, Fig. 13: 4; Fig. 14: 4). This shows that various flaking techniques were used depending on the quality of raw material.

On the topic of shaping patterns, two handaxes are bifacially shaped, five are partly bifacial and two are unifacial. The picks and cleaver are all partly bifacial, indicating that partly bifacial was the main shaping pattern. There is an average of 19.1 shaping scars per piece, with a range between 35 and seven scars for individual pieces, showing a relatively high degree of variation (see Table 3). This also shows that toolmakers may employ intensive shaping sometimes. Secondary scars (with focus on the edges) are on average higher in number than primary shaping scars (with focus on the whole body), with a ratio of 13.0:6.3 secondary to primary scars (Table 4). This demonstrates that shaping was mainly focused on the edges of LCTs, although invasive flaking was conducted to obtain a predetermined form. Moreover, for the LCTs made on large flake blanks, average shaping scars on the ventral surface (usually flatter than the dorsal face) are almost twice as numerous as scars on the dorsal surface with a ratio of 11.0:5.2 (ventral to dorsal) (Table 4). This indicates sophisticated shaping technology compared with the relatively easier shaping of a convex surface into a flat one observed by Boëda et al. (1990) and de la Torre (2009).

Table 3
Data for LCTs from both excavation and surface collection at the Shuangshu site. Weight in grams, measurements in mm.

Number	Type	Weight	Length	Breadth	Thickness	L/B	B/L	T/B	Raw material	Blank	Scar counts
Excavated											
SS-244	Handaxe	1724.00	203.00	108.00	85.00	1.88	0.53	0.79	Quartz	Cobble	35
SS-495	Handaxe	828.00	179.00	101.00	60.00	1.77	0.56	0.59	Trachyte	Flake	29
SS-545	Handaxe	310.00	141.00	76.00	25.00	1.86	0.54	0.33	Quartz phyllite	Bipolar flake	12
SS-546	Handaxe	424.00	151.00	82.00	37.00	1.84	0.54	0.45	Quartz phyllite	Cobble	18
SS-562	Handaxe	1186.00	195.00	97.00	70.00	2.01	0.50	0.72	Quartz phyllite	Cobble	19
SS-576	Handaxe	456.00	147.00	83.00	35.00	1.77	0.56	0.42	Quartz phyllite	Flake	16
SS-T1	Handaxe	356.00	128.00	97.00	25.00	1.32	0.76	0.26	Trachyte	Flake	15
SS-T3	Handaxe	566.00	173.00	108.00	30.00	1.60	0.62	0.28	Quartz phyllite	Flake	7
SS-T10	Handaxe	426 (min)	125 (min)	92.00	26.00			0.28	Trachyte	Inderterminate	Inderterminate
SS-T21	Handaxe	1220.00	183.00	121.00	47.00	1.51	0.66	0.39	Trachyte	Cobble	28
SS-13	Pick	946.00	162.00	93.00	58.00	1.74	0.57	0.62	Quartz phyllite	Split cobble	12
SS-487	Pick	1384.00	201.00	103.00	66.00	1.95	0.51	0.64	Quartz phyllite	Cobble	22
SS-493	Cleaver	2088.00	246.00	143.00	62.00	1.72	0.58	0.43	Quartz phyllite	Flake	16
Surface											
10	Handaxe	494.00	135.99	81.27	47.54	1.67	0.60	0.58	Quartz phyllite	Cobble	15
19	Handaxe	318.00	126.33	78.10	32.41	1.62	0.62	0.41	Quartz phyllite	Bipolar flake	14
23	Handaxe	604.00	131.42	82.94	50.23	1.58	0.63	0.61	Quartz phyllite	Split cobble	20
26	Handaxe	572.00	134.61	77.22	57.07	1.74	0.57	0.74	Quartz phyllite	Cobble	29
28	Handaxe	760 (min)	141 (min)	100.33	49.88			0.50	Quartz phyllite	Bipolar flake	22
30	Pick	522	129.72	90.47	52.55	1.43	0.70	0.58	Quartz phyllite	Cobble	16
40	Pick	1284	193.26	127.95	58.33	1.51	0.66	0.46	Quartz phyllite	Flake	18
55	Cleaver	674 g	154.17	79.16	47.50	1.95	0.51	0.60	Quartz	Flake	30

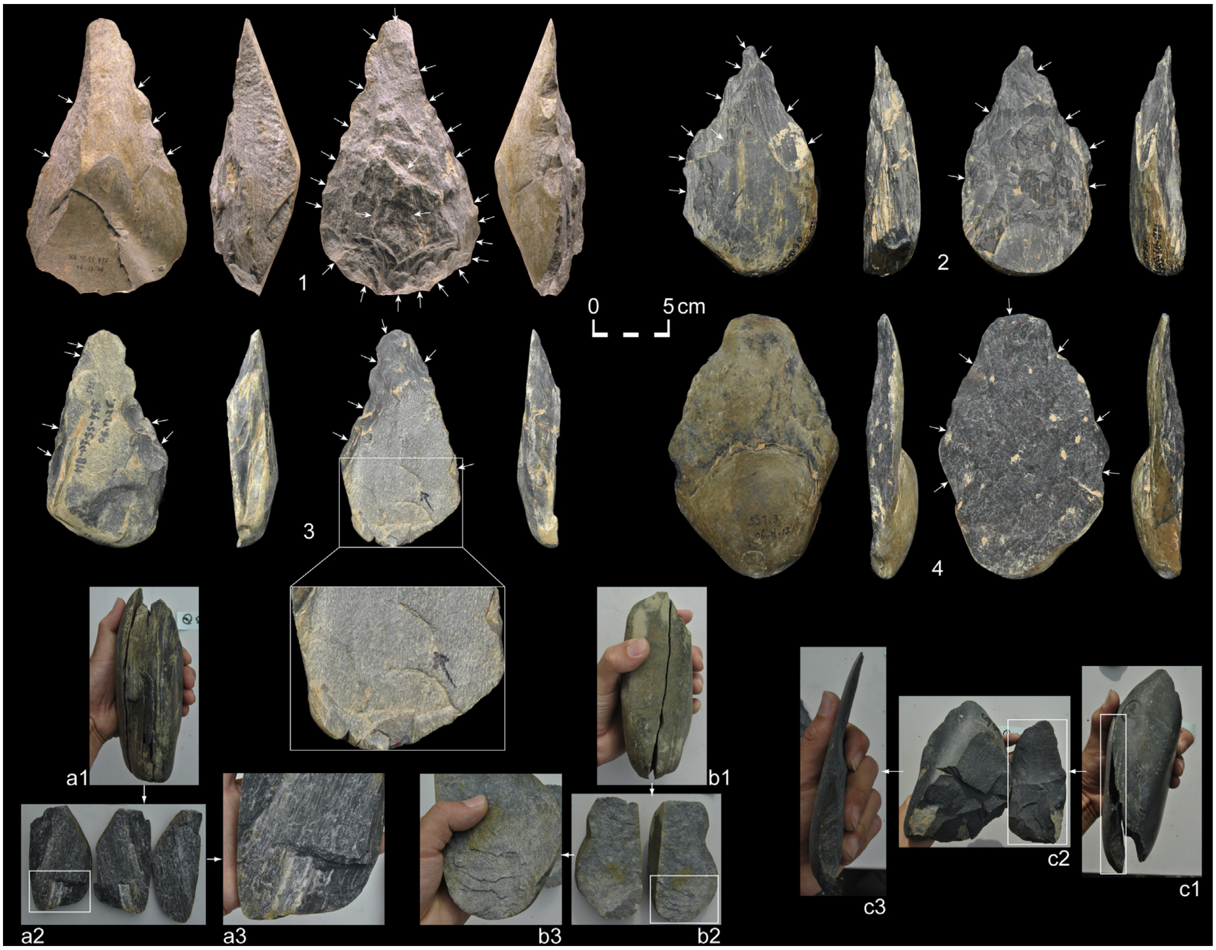

Fig. 13. Nos. 1–4 are Shuangshu handaxes made on flake blanks: (1) SS-495, trachyte handaxe; (2) SS-576, quartz phyllite handaxe; (3) SS-545, quartz phyllite handaxe made on a bipolar flake; (4) SS-T3, quartz phyllite handaxe made on a thrown flake. a and b represent the experimental bipolar technique using quartz phyllite and trachyte respectively, with crushing visible at the bottom of two bipolar flakes (a3 and b3). c represents the experimental throwing technique (a cobble thrown against an anvil stone) using quartz phyllite; note the small thickness of the flake.

4.5. Hammerstones and anvils

There were five hammerstones, four in quartz and one in sandstone. The average dimensions are 116.8L × 97.6 W × 58.4 T (mm) and the average weight 979.6 g. Hammerstones are mainly oval-shaped with flat-convex or double-convex cross sections. The use traces are small pits that are always concentrated on the convergent part of the cobble surfaces, indicating the skillful control of striking direction (Fig. 9: 5).

Two anvils were also found. One is quartz phyllite and the other is sandstone. The average dimensions of the two anvils are 260.0L × 205.0 W × 140.0 T (mm) and they have an average weight of 9976.0 g. The giant anvils at the site were likely not placed there by hydraulic processes, but rather they reflect the intentional transport of raw materials by hominids.

4.6. Manuports

Thirty manuports were discovered on site. Among them, 19 are quartz phyllite, eight are quartz and three are trachyte. The average dimensions are 108.4L × 79.2 W × 47.1 T (mm) and the average weight is 783.5 g. The size of the manuports is similar to the size of the cores and hammerstones, indicating that the manuports may have been wanted for cores or hammerstones. To a certain degree, the appearance of manuports combined with the hammerstones and anvils unearthed from the site suggest that the small-medium sized lithics were probably produced on-site.

5. Discussion

5.1. Technological strategies and attributes of the Shuangshu lithic assemblage

Analysis of the technology at the Shuangshu site show that there are two reduction sequences taking place. One is expressed by the small-medium sized artifact production, and the second reduction sequence is represented by the LCTs that are usually seen as the diagnostic implement of the Acheulean technocomplex. Raw materials, which were abundant in the nearby river banks, were procured by hominids and did not require long distance transport. There is a clear dichotomy in the raw material exploitation strategies in the two sequences, which demonstrates the preferences in the raw materials selectivity. Quartz was commonly used in the first sequence, while quartz phyllite and trachyte were predominately used in the making of LCTs.

The technology utilized in the small-medium artifacts production is simple and opportunistic, as seen through the technological analysis of flakes, cores and retouched pieces. The scar number on cores is low (3.8 on average) and most cores are simple chopper-cores, with the flaking platforms dominated by cortex or

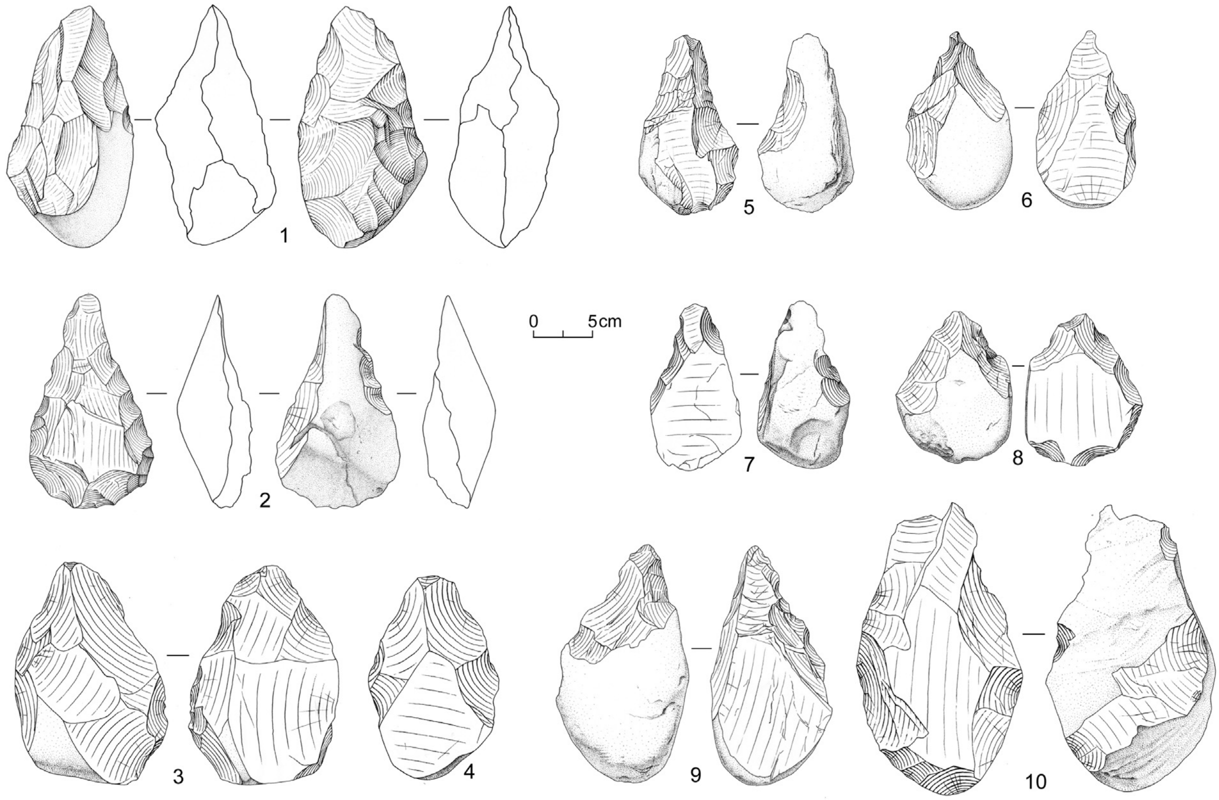

Fig. 14. LCTs from Shuangshu: (1–7) handaxes (see Fig. 12 and 13 for piece numbers); (8) SS-T1, trachyte handaxe made on a flake; (9) SS-487, quartz phyllite pick made on a split cobble; (10) SS-493, quartz phyllite cleaver made on a flake.

unprepared flaking surfaces. With regards to flakes, most have cortical or plain platforms, with irregular scar patterning dominating on the dorsal surface. For retouched pieces, the number of retouch scars is low and these can be regarded as the informal tools in the assemblage. All of these represent an expedient technological strategy used in the production of small-medium sized artifacts, which may be related to the abundant raw materials near the site. Meanwhile, the presence of all varieties of detached pieces–flakes, chunks and debris, the cores, the hammerstones, the anvils, and the manuports–indicates that the production, use and discard of small-medium sized artifacts was conducted on-site, and therefore represents a complete reduction sequence. In contrast, the technology of making LCTs is different to the small-medium sized artifact production. The blanks for making LCTs are large flakes, cobbles and split cobbles, among which large flakes are the most common blank (58.3%), although the occurrence of several blank types shows flexibility in the flaking techniques. The features of flake scars retained in the LCTs allow us to deduce that there was no core preparation before flaking occurred. The flaking was directly carried out on the carefully selected cobbles, and primary (or cobble opening) flakes were used to make LCTs. With respect to shaping, the number of secondary scars (13.0 on average) is higher than the number of primary shaping scars (6.3 on average), indicating that flaking was concentrated on the margins of the LCTs and these hominids paid more attention to getting effective edges.

Table 4
Mean and SD (in parentheses) of scar counts according to the type of shaping. PS means the number of primary scars; SS means the number of secondary scars; DFS means the number of scars on the dorsal face (for cobble blanks, convex face is treated as the dorsal); VFS means the number of scars on the ventral face.

Type	PS	SS	DFS	VFS
Handaxes ($N = 9$)	6.3 (2.8)	13.8 (6.8)	7.1 (4.9)	13.0 (6.7)
Picks ($N = 2$)	7.5 (2.8)	12.5 (4.2)	6.5 (2.1)	10.5 (4.9)
Cleaver ($N = 1$)	6	10	5	11
Combined ($N = 12$)	6.3 (2.5)	13 (6.1)	6.8 (4.3)	12 (6.0)

Table 5
Comparison of scar counts of handaxes from Chinese sites with western Acheulean sites.

	Scar counts				
	Age	*N*	Mean	SD	Reference
China					
DRR-Shuangshu	Middle Pleist	9	19.9	9.0	This paper
Baise-Fengshudao	ca. 803 ka	104	27.0	8.5	Wang et al., 2014b
Baise	ca. 803 ka	33	24.7	10.5	Hou et al., 2000
India					
Hunsgi	Middle Pleist	38	22.1	10.3	Sharon, 2007
Chirki	Middle Pleist	40	21.6	7.26	Sharon, 2007
West Asia					
Gesher Benot Ya'aqov II-6	<0.78 Ma	203	26.0	11.2	Sharon, 2007
Africa					
KGA6-A1 Locus C	~1.75 Ma	4	12.3	5.7	Beyene et al., 2013
KGA4-A2	~1.6 Ma	19	12.3	7.5	Beyene et al., 2013
KGA10-A11	~1.45 Ma	16	10.6	5.7	Beyene et al., 2013
KGA7-A1,A2,A3	~1.4 Ma	17	17.1	7.7	Beyene et al., 2013
KGA12-A1	~1.25 Ma	30	18.2	7.3	Beyene et al., 2013
KGA20-A1,A2	~0.85 Ma	19	30.4	10.9	Beyene et al., 2013
STIC	<0.7 Ma	70	24.8	11.3	Sharon, 2007
Ternifine	~0.7 Ma	48	19.1	10.5	Sharon, 2007
Grotte des Ours	~0.4 Ma	51	21.6	9.9	Sharon, 2007
Olorgesailie	0.7–0.4 Ma	[a]	25.4	9.1	Isaac, 1977

[a] Isaac (1977) only provides a table for the range of handaxe numbers utilized for scar counts (343–666).

Table 6
Comparisons between excavated and surface collected handaxes at the Shuangshu site. Weight in grams, measurements in mm.

	Excavated		Surface		t-statistic	p-value
	N	Mean	N	Mean		
Weight	9	785.56	4	497.00	1.077	0.313
Length	9	166.67	4	132.09	3.615	<0.05
Breadth	10	96.50	5	83.97	1.811	0.093
Thickness	10	44.00	5	47.43	−0.343	0.737
L/B	9	1.73	4	1.65	0.678	0.515
T/B	10	0.45	5	0.57	−1.250	0.233
Scar counts	9	19.9	5	20.0	−0.025	0.981

Table 7
Comparisons between excavated handaxes at the Shuangshu site and the surface collected handaxes from the DRR. Weight in grams, measurements in mm.

	Excavated		Surface		t-statistic	p-value
	N	Mean	N	Mean		
Weight	9	785.6	77	823.4	−0.266	0.791
Length	9	166.7	77	165.6	0.099	0.922
Breadth	10	96.5	86	96.5	−0.005	0.996
Thickness	10	44.0	86	46.5	−0.371	0.718
L/B	9	1.7	77	1.7	0.039	0.969
T/B	10	0.5	86	0.5	−0.583	0.573
Scar counts	9	19.9	75	18.0	0.604	0.561

However, the primary shaping, i.e. the invasive flaking, did play an important role in shaping of the whole body of LCTs, which is well demonstrated by the convergent distals and the shaped bodies of handaxes and picks. Table 5 presents a preliminary comparison of flake scar numbers of handaxes from Chinese sites and western Acheulean sites. It shows that the mean scar count of the Shuangshu handaxes ($n = 19.9$) is close to that of other sites, but at the lower end of the range. The mean scar counts on handaxes at Ternifine (ca 0.7 Ma) and five Early Acheulean localities (>1.0 Ma) at KGA are lower than at Shuangshu (Table 5).

Although the number of excavated LCTs at the Shuangshu site is low, we argue that they are an important type purposefully made by toolmakers and not a fortuitous development related to choppers. To demonstrate this, we conducted statistical comparisons between excavated handaxes and those from systematic surface collection in the DRR (Kuman et al., in press; Li et al., in press-b). If there are no statistically significant differences, it would support our argument that even if excavated examples are smaller in number, they are a consistent tool type, and probably penecontemporaneous with the more numerous surface-collected examples. At Shuangshu, five surface collected handaxes (see Table 3 for individual data) are compared with the 10 excavated handaxes from the site (Table 6). To further demonstrate the provenience of handaxes collected from the whole DRR, we then compare the 86 handaxes collected from the third terrace of the DRR with the ten handaxes excavated from the Shuangshu site (Table 7). In the comparative study, weight, length, breadth, thickness and the indices of L/B and T/B are used. In addition, the numbers of scars are considered. The Student's *t*-statistic in Table 6 shows that there is no significant difference in most cases between handaxes from excavation and from surface collection at Shuangshu. The only significant variation ($p < 0.05$) is the length, which is probably due to the small size of the sample. If a larger sample used, it is clear that there would be no significant difference (Table 7). Thus, it is reasonable to infer that the surface collected handaxes are penecontemporaneous with the excavated examples and, therefore, that handaxes excavated from the Shuangshu site were not an occasional production. Rather they reflected intentional type, most probably used for functions different to those for which the hominids used the small-medium sized artifacts.

The characteristic traits used to define typical Acheulean technology include (1) the ability to knock off large flake, (2) the ability to flake invasively and shape tools purposefully with predetermination or preconception of form, and (3) the standardization of tool technique (Isaac, 1969; Semaw et al., 2009; Beyene et al., 2013). Technological analysis of LCTs at the Shuangshu site on these traits

Table 8
Artifact numbers and densities for individual sites in China. LCT numbers are provided, with handaxe densities calculated by square meter.

Region	Site	Age	Excavation area	Artifacts		LCTs		LCTs from surface collection of the site	References
				N	Density (/m2)	N	Handaxe density (/m2)		
DRR (T3)	Shuangshu	Middle Pleist	1435 m^2	706	0.492	13 (10 handaxes, 2 picks and 1 cleaver)	0.007	8 (5 handaxes, 2 picks and 1 cleaver)	This paper; Li et al., in press-a
DRR (T3)	Beitaishanmiao	Middle Pleist	800 m^2	277	0.346	7 picks	[a]	27 (24 handaxes, 3 picks)	Zhou et al., 2009; Kuman et al., in press
DRR (T3)	Shuiniuwa	Middle Pleist	675 m^2	301	0.446	1 handaxe	0.001	5 (3 handaxes, 2 picks)	Chen et al., 2014; Kuman et al., in press
DRR (T3)	Pengjiahe	Middle Pleist	600 m^2	264	0.440	8 picks	[a]	7 (3 handaxes, 4 picks)	Pei et al., 2008; Kuman et al., in press
DRR (T3)	Beitaishanmiao II	Middle Pleist	500 m^2	159	0.318	9 (4 handaxes, 5 picks)	0.008	–	Fang et al., 2012
DRR (T3)	Guochachang II	Middle Pleist	500 m^2	150	0.300	4 (3 handaxes, 1 pick)	0.006	17 (6 handaxes, 9 picks and 2 cleavers)	Li et al., 2013; Kuman et al., in press; Li et al., in press-a
DRR (T3)	Waibiangou	Middle Pleist	500 m^2	121	0.242	1 handaxe	0.002	2 (1 handaxe, 1 pick)	Li et al., 2011; Recorded by H. Li
DRR (T3)	Datubaozi	Middle Pleist	300 m^2	58	0.193	1 handaxe	0.003	3 picks	Li et al., 2011; Recorded by H. Li
DRR (T2)	Liuwan I	Late Pleist	500 m^2	177	0.354	5 (3 handaxes, 2 picks)	0.006	5 (1 handaxe, 3 picks and 1 cleaver)	Feng et al., 2012; Recorded by H. Li
DRR (T2)	Houfang	Early Late Pleist	400 m^2	162	0.405	3 (2 handaxes, 1 pick)	0.005	–	Li and Sun, 2013
DRR (T2)	Dishuiyan	100–50 ka	–	>600	–	>20 handaxes	–	–	Liu and Feng, 2014
Baise Basin	Nanbanshan	ca. 803 ka	2500 m^2	176	0.070	11 (2 handaxes, 9 picks)	0.0008	7 handaxes	Wang et al., 2008; Huang, 2003
Baise Basin	Fengshudao	ca. 803 ka	49.3 m^2	155	3.144	6 (5 handaxes, 1 pick)	0.101	99 handaxes	Wang et al., 2014b

[a] At Beitaishanmiao, two of these picks were reclassified as handaxes (Kuman et al., in press); and at Pengjiahe, one handaxe was identified (Kuman et al., in press).

Table 9
Comparison of the thickness (in mm) of East Asian handaxes with western Acheulean examples.

Locality	Age	*N*	Mean	SD	CV	References
East Asia						
DRR	Middle Pleist	96	46.25	12.48	26.98	Li et al., in press-a
Baise	~0.8 Ma	168	69.87	13.67	19.56	Huang, 2003; Wang et al., 2014b
Luonan	<0.5 Ma	236	58.41	13.46	23.04	Wang, 2007
IHRB	<0.35 Ma	58	60.19	12.92	21.46	Norton et al., 2006
South Asia						
Anagwadi	Middle Pleist	15	45.73	6.04	13.21	Szabo et al., 1990; Petraglia and Shipton, 2008
Fatehpur V	0.35–0.16 Ma	11	40.91	11.36	27.77	Szabo et al., 1990; Petraglia and Shipton, 2008
Gulbal II	0.35–0.16 Ma	12	47.50	9.65	20.32	Szabo et al., 1990; Petraglia and Shipton, 2008
Hunsgi II	0.35–0.16 Ma	18	52.22	10.60	20.30	Szabo et al., 1990; Petraglia and Shipton, 2008
Hunsgi V	0.35–0.16 Ma	45	48.44	9.99	20.62	Szabo et al., 1990; Petraglia and Shipton, 2008
Mudnur VIII	0.35–0.16 Ma	9	61.11	9.28	15.19	Szabo et al., 1990; Petraglia and Shipton, 2008
Teggihalli II	Middle Pleist	9	33.86	11.54	34.08	Szabo et al., 1990; Petraglia and Shipton, 2008
Yediyapur I	0.35–0.16 Ma	10	36.00	5.16	14.33	Szabo et al., 1990; Petraglia and Shipton, 2008
Yediyapur IV	0.35–0.16 Ma	11	42.73	11.04	25.84	Szabo et al., 1990; Petraglia and Shipton, 2008
Yediyapur VI	0.35–0.16 Ma	21	42.86	13.09	30.54	Szabo et al., 1990; Petraglia and Shipton, 2008
West Asia						
Azraq Lion Spring	Middle Pleist	42	43.97	9.68	22.02	Petraglia and Shipton, 2008
Dawadmi 207–76	Middle Pleist?	27	52.04	22.02	42.31	Petraglia and Shipton, 2008
Wadi Fatima	Middle Pleist?	15	49.67	9.80	19.73	Petraglia and Shipton, 2008
West Europe						
Boxgrove	~0.5 Ma	182	30.59	5.66	18.51	Marshall et al., 2002
Broom Pits	0.29–0.23 Ma	241	36.22	10.20	28.16	Marshall et al., 2002
Corfe Mullen	0.5–0.38 Ma	131	37.94	12.30	32.42	Marshall et al., 2002
Cuxton	0.43–0.23 Ma	205	44.15	11.80	26.73	Marshall et al., 2002
North Africa						
Grotte des Ours	~0.4 Ma	40	43.81	6.79	15.50	Marshall et al., 2002
STIC	<0.7 Ma	82	54.64	10.64	19.47	Marshall et al., 2002
East Africa						
Olduvai EF-HR, Bed II	1.6Ma	22	46.91	10.25	21.85	Recorded by K. Kuman; Leakey, 1971
Olduvai Masek Beds	0.7–0.4 Ma	125	41.25	7.75	18.79	Marshall et al., 2002
South Africa						
Sterkfontein	~1.6 Ma	10	47.00	9.51	20.23	Recorded by K. Kuman; Kuman 1994, 1998; Field 1999
Rietputs 15 Pit1	1.72 ± 0.16 Ma	9	40.89	6.62	16.19	Recorded by K. Kuman; Gibbon et al., 2009
Rietputs 15 Pit5 (A)	1.32 ± 0.21Ma	77	41.58	9.70	23.33	Recorded by K. Kuman; Gibbon et al., 2009; Leader, 2009
Elandsfontein	1.0–0.6 Ma	232	40.13	11.19	27.88	Marshall et al., 2002
Amanzi Springs	Middle Pleist	133	53.69	11.22	20.90	Marshall et al., 2002
Doornlaagte	1.0–0.5 Ma	44	59.03	11.76	19.92	Marshall et al., 2002
Cave of Hearths	0.45/0.5 Ma	32	45.11	10.01	22.19	Marshall et al., 2002

indicates that all three are present at the site. Thus, it is sound to suggest that the attributes of Shuangshu site can be described as Acheulean, although its origins are much debated. However, regarding the attributes of handaxe-bearing sites in China, there are arguments that they cannot be classified as typical Acheulean, mainly because of their low frequencies and their noticeably morphological difference with western Acheulean handaxes (Norton et al., 2006; Lycett, 2007; Norton and Bae, 2008; Lycett and Bae, 2010; Lycett and Norton, 2010; Wang et al., 2012, 2014b). In following sections, we focus our discussions on these two points.

5.2. *The meaning of the low number of handaxes in the Chinese handaxe-bearing sites*

It is argued that one of the characteristic traits of the East Asian handaxe-bearing sites lies in the low number of handaxes from excavation sites (Norton et al., 2006; Norton and Bae, 2008). This argument is further supported by the Shuangshu site in this paper. Only 13 LCTs (including ten handaxes) were unearthed. However, the total number of artifacts (706) is also low for the size of the excavation area (1435 m^2). This can be seen as a pattern, as sites excavated at different handaxe-bearing regions in East Asia display the same quality. In Table 8, we provide the available information of the excavated handaxe sites from terrace three and terrace two of the DRR (eight sites on terrace three and three sites on terrace two), and from the Baise Basin (two sites). It shows clearly that both the number of handaxes and the overall size of complete assemblages is low for the size of the excavation area. The highest density of handaxes occurred at the Fengshudao site in the Baise Basin, where six LCTs including five handaxes were unearthed and the density of handaxes is 0.101/m^2. Nevertheless, the total number of artifacts is low, with only 155 specimens excavated from an area of 49.3 m^2 (Wang et al., 2014b). In contrast, the lowest density of handaxes (0.001/m^2) was found at the Shuiniuwa site in the DRR, with only one handaxe unearthed. The total number of artifacts at the Shuiniuwa site was low, with 301 specimens excavated from a 675 m^2 area (Chen et al., 2014). The Nanbanshan site in the Baise Basin had the lowest density of total artifacts; only 176 specimens were unearthed from an area of 2500 m^2. Of these, two were handaxes and nine were picks (Wang et al., 2008).

The comparative data provided here comfortably supports Norton et al.'s (2006), Norton and Bae (2008) observation. But, contrary to their argument that the low number of handaxes in the sites would not support the label true Acheulean to describe the East Asian handaxe-bearing sites, we suggest that the number of handaxes in a site is not the key criterion to judge if the site is true Acheulean or not. Rather it is the consideration of technological elements. We have proposed elsewhere that the proportion of LCTs in sites can be understood as a by-product of behavioral (or social) processes (Li et al., in press-b). The demographic model, for instance, has recently been considered as one of the most potent explanatory factors (Lycett and von Cramon-Taubadel, 2008; Lycett and Norton, 2010; Lycett and Bae, 2010; Kuman et al., in press). Based on the theory of genetic drift in population genetics, Lycett and Norton (2010) predict that the relatively smaller effective population size, which likely results from a combination of bio-

Table 10
Student's *t*-test comparing handaxe thickness. *p*-value <0.05 indicate significant differences and *p*-value <0.001 indicates very significant differences. Detailed information of the handaxe sites are given in Table 9.

	DRR	Baise	IHRB	Boxgrove	Broom Pits	Corfe Mullen	Cuxton	Grotte des Ours	STIC	Olduvai EF-HR, Bed II	Olduvai Masek Beds	Sterkfontein	Rietputs 15 Pit1	Rietputs 15 Pit5 (A)	Elandsfontein	Amanzi Springs	Doornlaagte	Cave of Hearths
DRR	–	<0.001	<0.001	<0.001	<0.001	<0.001	0.158	0.145	<0.001	0.819	<0.001	0.855	0.054	<0.05	<0.001	<0.001	<0.001	0.640
Baise	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
IHRB	<0.001	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.641	<0.001
Boxgrove	<0.001	<0.001	<0.001	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Broom Pits	<0.001	<0.001	<0.001	<0.001	–	0.173	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.175	<0.001	<0.001	<0.001	<0.001	<0.001
Corfe Mullen	<0.001	<0.001	<0.001	<0.001	0.173	–	<0.001	<0.001	<0.001	<0.05	<0.05	<0.05	0.253	<0.05	0.085	<0.001	<0.001	<0.05
Cuxton	0.158	<0.001	<0.001	<0.001	<0.001	<0.001	–	0.802	<0.001	0.293	<0.05	0.453	0.197	0.065	<0.001	<0.001	<0.001	0.662
Grotte des Ours	0.145	<0.001	<0.001	<0.001	<0.001	<0.001	0.802	–	<0.001	0.212	0.064	0.227	0.248	0.152	<0.05	<0.001	<0.001	0.531
STIC	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	–	<0.05	<0.001	<0.05	<0.001	<0.001	<0.001	0.540	<0.05	<0.001
Olduvai EF-HR, Bed II	0.819	<0.001	<0.001	<0.001	<0.001	<0.05	0.293	0.212	<0.05	–	<0.05	0.981	0.116	<0.05	<0.05	<0.05	<0.001	0.524
Olduvai Masek Beds	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.05	0.064	<0.001	<0.05	–	<0.05	0.892	0.799	0.268	<0.001	<0.001	<0.05
Sterkfontein	0.855	<0.001	<0.001	<0.001	<0.001	<0.05	0.453	0.227	<0.05	0.981	<0.05	–	0.127	0.100	0.057	0.069	<0.05	0.602
Rietputs 15 Pit1	0.054	<0.001	<0.001	<0.001	0.175	0.253	0.197	0.248	<0.001	0.116	0.892	0.127	–	0.835	0.840	<0.001	<0.001	0.242
Rietputs 15 Pit5(A)	<0.05	<0.001	<0.001	<0.001	<0.001	<0.05	0.065	0.152	<0.001	<0.05	0.799	0.100	0.835	–	0.308	<0.001	<0.001	0.090
Elandsfontein	<0.001	<0.001	<0.001	<0.001	<0.001	0.085	<0.001	<0.05	<0.001	<0.05	0.268	0.057	0.840	0.308	–	<0.001	<0.001	<0.05
Amanzi Springs	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.540	<0.05	<0.001	0.069	<0.001	<0.001	<0.001	–	<0.05	<0.001
Doornlaagte	<0.001	<0.001	0.641	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.05	–	<0.001
Cave of Hearths	0.640	<0.001	<0.001	<0.001	<0.001	<0.05	0.662	0.531	<0.001	0.524	<0.05	0.602	0.242	0.090	<0.05	<0.001	<0.001	–
Significant differences (%)	**64.7**	**100.0**	**94.1**	**100.0**	**88.2**	**82.4**	**58.8**	**52.9**	**94.1**	**64.7**	**76.5**	**47.1**	**35.3**	**58.8**	**70.6**	**88.2**	**94.1**	**58.8**

geographical, topographical and dispersal factors, may be an underlying cause of the sporadic occurrences of handaxe technology both geographically and temporally. According to the pattern of numbers revealed in Table 8, we are in agreement with Lycett and Norton's opinion that the relatively small effective population size in East Asia is probably the reason for the low number of handaxes, as well as the small size of assemblages in the sites. However, we suggest (contra Lycett and Norton) that although the population size is relatively small, the (handaxe) technological transmission from generation to generation was uninterrupted and finally formed a stable social or cultural tradition in a given region. The findings of handaxes on different terraces of the DRR offer evidence for this (Pei et al., 2008; Zhou et al., 2009; Feng et al., 2012; Li and Sun, 2013; Li et al., 2013; Liu and Feng, 2014; Chen et al., 2014; Kuman et al., in press). The systematic dating of handaxe-bearing sites on different terraces in the future will further test this assumption.

In addition to the demographic explanation, the usage strategy of the sites and the high mobility of hominids are also probable factors in the low number of handaxes and total artifacts (Gao and Pei, 2006; Gao, 2013). The relatively uniform river terrace habitat and the stable sub-tropical climate and resources of DRR in the Pleistocene provided a good environmental setting for frequent mobility from one site to another homogeneous site, and therefore the occupation of the terrace sites could be ephemeral. The expansive intermountain basin area and the developed and mutually related water system appear to have provided space and routes for high mobility. This explanation is supported by the recent discovery of handaxe sites in the vicinities of the DRR, for example, the Hanzhong Basin in the upper valley of the Han River and the Shangdan Basin in the upper valley of the Dan River (Wang et al., 2013; 2014a). However, greater concentration of handaxes did seem to happen at some sites, such as the Beitaishanmiao site in the DRR (27 LCTs including 24 handaxes were retrieved; see Kuman et al., in press) and the Fengshudao in the Baise Basin (99 handaxes were retrieved; see Wang et al., 2014b). Hou et al. (2000) also argued that there is a biased spatial distribution of LCTs in the Baise Basin, with Acheulean-like forms limited to the western third of the basin. Whether this a place-specific pattern or just sample bias is the question that needs to be addressed in future research, especially combined with the geographic and raw material features around the sites.

5.3. The inter-regional comparison of handaxe thickness

We argued above that the handaxe industry in the DRR can be considered true Acheulean, although the numbers of handaxes are relatively small. Here, we further demonstrate this through the inter-regional comparison of one measurement, thickness, which is widely considered to be another characteristic variable when comparing handaxes from the East and the West (Norton et al., 2006; Norton and Bae, 2008; Petraglia and Shipton, 2008; Shipton and Petraglia, 2010; Lycett and Bae, 2010; Wang et al., 2014b). The East Asian materials used here are from the DRR and the Luonan Basin in central China (Li et al., in press-a; Wang, 2005, 2007), the Baise Basin in South China (Huang, 2003; Wang et al., 2014b), and the IHRB in South Korea (Norton et al., 2006). The western Acheulean sites are from South Asia (India), West Asia (Arabia and Jordan), West Europe (Britain) and Africa (Morocco, Tanzania, South Africa) (Marshall et al., 2002; Petraglia and Shipton, 2008). The ages of these handaxe assemblages span from the beginning of Acheulean technology (~1.72 Ma) to the final stage of the Acheulean (~0.3 Ma).

The mean thickness of handaxes from each region or site is given in Table 9. We can see that the East Asian sites of Baise, Luonan and IHRB have higher mean thickness than most of the western Acheulean sites, whereas the mean thickness of the DRR handaxes (46.25 mm) overlaps considerably with some western Acheulean sites (both early and late Acheulean sites). Student's *t*-statistic of the mean thickness of handaxes between pairs of regions or sites in Table 10 indicates that the three East Asian handaxe assemblages, i.e. DRR, Baise and IHRB, are significantly different from each other ($p < 0.001$), showing distinct variability within the East Asian sites. Of these, the Baise handaxes are significantly different from all other handaxe assemblages from the East and the West, while the IHRB handaxes have a 94% difference, and the DRR handaxes have a lower difference of 64.7%. This means the thickness of DRR handaxes is much closer to that of the western Acheulean examples (Table 10). Detailed examination of mean thickness among western Acheulean sites, however, also indicates considerable variability. Of the 15 western Acheulean sites, nine of them (60%) show the same or an even higher percentage (≥64.7%) of significant difference when compared with other sites (Table 10). According to the statistical results presented here, we argue that thickness is likely not a reliable variable to demonstrate the difference between the East and the West. As we have discussed elsewhere (see Li et al., in press-a), some factors, such as the quality of raw materials, the blank types or the extent of reduction could easily result in significant variability of handaxe thickness, regardless of geographical differences.

6. Conclusions

In this paper, the detailed technological analysis of the in situ artifact assemblage in the Shuangshu site, as well as the intra- and inter-regional comparisons on some characteristic traits of handaxes allow the reconstruction of full technological strategies and behaviors of early hominids. The features revealed in the study are as follows:

- the procurement of raw materials were from the locally available river cobbles;
- the preferential selection of different raw materials for different technical processes, which indicates a good knowledge of raw material properties;
- the predominant use of quartz in the production of small-to-medium sized artifacts, which dominates the whole assemblage and shows an expedient technological strategy;
- the predominant use of quartz phyllite and trachyte in the production of LCTs, which displays the technical criteria required to define Acheulean technology;
- the co-existence of two distinct reduction sequences at the site indicates flexible technological strategies and the diverse survival needs;
- the comparative analysis of the number of handaxes indicates that both the LCTs and the total artifacts are generally low in numbers when compared with the large excavation area, and this was probably due to the relatively smaller population size and the high mobility of hominids;
- the comparative analysis on the thickness of handaxes indicates that it is not a reliable variable in demonstrating the handaxe differences between the East and the West.

In conclusion, the Shaungshu site provides us a window to research the technology and behavior of the hominids that lived in the Middle Pleistocene in central China. Given the importance of these materials, further work in the Danjiangkou Reservoir Region is still needed, especially on dating, site formation process, landscape use and the technological strategy contained in the in situ assemblages. These in-depth analyses in this region will give us a

better understanding of the technological and behavioral evolution of the Middle Pleistocene's populations in China.

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References

Archer, W., Braun, D.R., 2010. Variability in bifacial technology at Elandsfontein, Western cape, South Africa: a geometric morphometric approach. J. Archaeol. Sci. 37, 201–209.
Atlas of China, 2007, SinoMaps Press, Beijing.
Bahain, J.J., Falguères, C., Laurent, M., Voinchet, P., Dolo, J.M., Antoine, P., Tuffreau, A., 2007. ESR chronology of the Somme River terrace system and first human settlements in Northern France. Quat. Geochronol. 2, 356–362.
Beerten, K., Stesmans, A., 2006. The use of Ti centers for estimating burial doses of single quartz grains: a case study from an aeolian deposit similar to 2 Ma old. Radiat. Meas. 41 (4), 418–424.
Beerten, K., Stesmans, A., 2007. ESR dating of sedimentary quartz: possibilities and limitations of the signal-grain approach. Quat. Geochronol. 2, 373–380.
Beerten, K., Lomax, J., Clémer, K., Stesmans, A., Radtke, U., 2006. On the use of Ti centres for estimating burial ages of Pleistocene sedimentary quartz: multiple-grain data from Australia. Quat. Geochronol. 1, 151–158.
Beyene, Y., Katoh, S., WoldeGabriel, G., Hart, W.K., Uto, K., Sudo, M., Kondo, M., Hyodo, M., Renne, P.R., Suwa, G., Asfaw, B., 2013. The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia. Proc. Natl. Acad. Sci. 110 (5), 1584–1591.
Boëda, E., Geneste, J.M., Meignen, L., 1990. Identification de chaînes opératoires lithiquea du Paléolithique ancient et moyen. Paleo 2, 43–80.
Cande, S.C., Kent, D.V., 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. J. Geophys. Res. 100, 6093–6095.
Chen, Q.J., Chen, X.Y., Fang, Q., 2014. A preliminary report on the excavation of the Shuiniuwa Paleolithic site in the Danjiangkou Reservoir Regions. Acta Anthropol. Sin. 33 (1), 27–38 (in Chinese, with English abstract).
Chen, T.M., Yang, Q., Hu, Y.Q., Bao, W.B., Li, T.Y., 1997. ESR dating of tooth enamel from Yuxian *Homo erectus* site, China. Quat. Sci. Rev. 16, 455–458.
Chen, T.M., Yang, Q., Hu, Y.Q., Li, T.Y., 1996. ESR dating on the stratigraphy of Yunxian *Homo erectus*, Hubei, China. Acta Anthropol. Sin. 15 (2), 114–118 (in Chinese, with English abstract).
Clark, J.D., 2001. Variability in primary and secondary technologies of the Later Acheulian in Africa. In: Milliken, S., Cook, J. (Eds.), A Very Remote Period Indeed: Papers on the Palaeolithic Presented to Derek Roe. Oxbow Books, Oxford, pp. 1–18.
de la Torre, I., 2009. Technological strategies in the lower Pleistocene at Peninj (West of Lake Natron, Tanzania). In: Schick, K., Toth, N. (Eds.), The Cutting Edge: New Approaches to the Archaeology of Human Origins. Stone Age Institute Press, Bloomington, pp. 93–113.
de la Torre, I., Mora, R., 2005. Technological Strategies in the Lower Pleistocene at Olduvai Beds I & II. In: Eraul, vol. 112. University of Liège Press, Liège.
De Lumley, H., Li, T.Y. (Eds.), 2008. Le Site de L'Homme de Yunxian. CNRS Editions, Paris.
Diez-Martín, F., Eren, M.I., 2012. The early Acheulean in Africa: past paradigms, current ideas, and future directions. In: Domínguez-Rodrigo, M. (Ed.), Stone Tools and Fossil Bones: Debates in the Archaeology of Human Origins. Cambridge University Press, Cambridge, pp. 310–357.
Fang, Q., Chen, Q.J., Lu, Y., 2012. A preliminary report on the excavation of the Beitaishanmiao Paleolithic site 2 at Danjiangkou, Hubei province. Acta Anthropol. Sin. 31 (4), 343–354 (in Chinese, with English abstract).
Feng, X.B., Wang, H., Wang, Z.H., Huang, X.C., Zhou, X.M., Zhang, J., 2012. A preliminary excavation report of an Upper Paleolithic site in Liuwan at Yunxian County, Hubei Province. Jianghan Archaeol. 123, 3–11 (in Chinese, with English abstract).
Field, A.S., 1999. An Analytical and Comparative Study of the Earlier Stone Age Archaeology of the Sterkfontein Valley (MSc dissertation). University of the Witwatersrand, Johannesburg, South Africa.
Gallotti, R., 2013. An older origin for the Acheulean at Melka Kunture (Upper Awash, Ethiopia): techno-economic behaviours at Garba IVD. J. Hum. Evol. 65, 594–620.
Gamble, C., Marshall, G., 2001. The shape of handaxes, the structure of the Acheulian world. In: Milliken, S., Cook, J. (Eds.), A Very Remote Period Indeed: Papers on the Palaeolithic Presented to Derek Roe. Oxbow Books, Oxford, pp. 19–27.
Gao, X., 2013. Paleolithic cultures in China: uniqueness and divergence. Curr. Anthropol. 54, S358–S370.
Gao, X., Pei, S.W., 2006. An archaeological interpretation of ancient human lithic technology and adaptative strategies in China. Quat. Sci. 26 (4), 504–513 (in Chinese, with English abstract).
Gibbon, R.J., Granger, D.E., Kuman, K., Partridge, T.C., 2009. Early Acheulean technology in the Vaal River gravels, South Africa, dated with cosmogenic nuclides. J. Hum. Evol. 56, 152–160.
Gu, H.L., Huang, C.C., Zhou, Y.L., Pang, J.L., Zha, X.C., Qiao, J., 2012. OSL dating of the Holocene eolian loess and palaeosol on the low terrace land in the upper Hanjiang River valley. Quat. Sci. 32 (3), 516–526 (in Chinese, with English abstract).
Guo, Y.Q., Huang, C.C., Pang, J.L., Zha, X.C., Zhou, Y.L., Zhang, Y.Z., Zhou, L., 2013. Sedimentological study of the stratigraphy of the site of *Homo erectus yunxianensis* in the upper Hanjiang River valley, China. Quat. Int. 300, 75–82.
Hou, Y.M., Potts, R., Yuan, B.Y., Guo, Z.T., Deino, A., Wang, W., Clark, J., Xie, G.M., Huang, W.W., 2000. Mid-Pleistocene Acheulean-like stone technology of the Bose Basin, South China. Science 287, 1622–1626.
Huang, P.H., Li, W.S., 1995. Landscape, quaternary strata and buried environment at estuary of the Quyuan River in Yunxian county, Hubei province. Jianghan Archaeol. 4, 3–86 (in Chinese, with English abstract).
Huang, Q.S., 2003. Bose Paleolithic Industry. Cultural Relics Press, Beijing (in Chinese, with English abstract).
Huang, W.B., Xu, X.F., Li, T.Y., 1987. A report of the Paleolithic site from Zhangnao Cave, Fang County Hubei Province. Acta Anthropol. Sin. 6 (4), 298–305 (in Chinese, with English abstract).
Huang, X.S., Zheng, S.H., Li, C.R., Zhang, Z.Q., Guo, J.W., Liu, L.P., 1996. Discovery of vertebrate fossils and Paleolithic artifacts in Danjiang submerging area and its implications. Vertebr. Palasiat. 34 (3), 228–234 (in Chinese, with English abstract).
Huang, Z.G., Zhang, W.Q., Chen, J.H., 1999. The change of natural zones and the evolution of red earth in China. Acta Geogr. Sin. 54 (3), 193–203 (in Chinese, with English abstract).
Isaac, G.L., 1969. Studies of early culture in East Africa. World Archaeol. 1 (1), 1–28.
Isaac, G.L., 1977. Olorgesailie: Archaeological Studies of a Middle Pleistocene Lake Basin in Kenya. University of Chicago Press, Chicago.
Jelinek, V., 1978. Statistical processing of anisotropy of magnetic susceptibility measured on group of sediments. Stud. Geophys. Geod. 22, 50–62.
Johnson, C.R., McBrearty, S., 2012. Archaeology of Middle Pleistocene lacustrine and spring paleoenvironments in the Kapthurin Formation, Kenya. J. Anthropol. Archaeol. 31, 485–499.
Kuman, K., 1994. The archaeology of Sterkfontein: past and present. J. Hum. Evol. 27, 471–495.
Kuman, K., 1998. The earliest South African industries. In: Petraglia, M., Korisettar, R. (Eds.), Early Human Behaviour in Global Context: the Rise and Diversity of the Lower Palaeolithic Record. Routledge Press, London, pp. 151–186.
Kuman, K., Li, C.R., Li, H., 2014. Large Cutting Tools in the Danjiangkou Reservoir Region, central China (in press). J. Hum. Evol..
Leader, G.M., 2009. The Early Acheulean in the Vaal River Basin, Rietputs Formation, Northern Cape Province, South Africa (MSc dissertation). University of the Witwatersrand, Johannesburg, South Africa.
Leakey, M.D., 1971. Olduvai Gorge, vol. 3. Cambridge University Press, Cambridge.
Li, C.R., Feng, X.W., Li, H., 2009. A study of the stone artifacts discovered in the Danjiangkou Reservoir area in 1994. Acta Anthropol. Sin. 28 (4), 337–354 (in Chinese, with English abstract).
Li, C.R., Li, H., Xu, Y., Lou, Y.S., Yang, X.A., 2011. Handaxes discovered at Palaeolithic sites of Waibiangou and Datubaozi in Danjiangkou Reservoir Region. Fossil 3, 66–72 (in Chinese).
Li, H., Kuman, K., Li, C.R., 2014a. Re-examination of the morphological variability of East Asian handaxes from a comparative perspective. World Archaeol. (in press).
Li, H., Li, C.R., Feng, X.W., 2012. A study on the stone artifacts from 2004 field investigation in Danjiangkou Reservoir Area, Hubei and Henan, China. Acta Anthropol. Sin. 31 (2), 113–126 (in Chinese, with English abstract).
Li, H., Li, C.R., Kuman, K., 2013. A preliminary report on the excavation of the Guochachang II Paleolithic site in the Danjiangkou Reservoir Region, Hubei province, China. Acta Anthropol. Sin. 32 (2), 144–155 (in Chinese, with English abstract).
Li, H., Li, C.R., Kuman, K., 2014b. Rethinking the “Acheulean” in East Asia: evidence from recent investigations in the Danjiangkou Reservoir Region, central China. Quat. Int. (in press).

Li, T.Y., Feng, X.B., 2001. Yunxian Man. Hubei Science and Technology Press, Wuhan (in Chinese, with English abstract).

Li, Y.H., Sun, X.F., 2013. A preliminary report on the excavation of the Houfang Paleolithic Site at Yunxian County, Hubei Province. Jianghan Archaeol. 126, 6–15 (in Chinese, with English abstract).

Liu, C.R., Yin, G.M., Deng, C.L., Han, F., Song, W.J., 2014. ESR dating of the Majuangou and Banshan Paleolithic sites in the Nihewan Basin, North China. J. Hum. Evol. 73, 58–63.

Liu, C.R., Yin, G.M., Fang, F., Voinchet, P., Deng, C.L., Han, F., Li, J.P., Song, W.J., Wang, D., Bahain, J.J., 2013. ESR dating of the Dongguotuo Palaeolithic site in the Nihewan Basin, northern China. Geochronometria 40, 348–354.

Liu, C.R., Yin, G.M., Gao, L., Bahain, J.J., Li, J.P., Lin, M., Chen, S.M., 2010. ESR dating of Pleistocene archaeological localities of the Nihewan Basin, North China – preliminary results. Quat. Geochronol. 5, 385–390.

Liu, C.R., Yin, G.M., Gao, L., Han, F., Zhang, H.P., 2011. Research advances in ESR geochronology of Quaternary deposits. Seismol. Geol. 2, 490–498 (in Chinese, with English abstract).

Liu, C.R., Yin, G.M., Gao, L., Li, J.P., Lin, M., 2009. Reliability of quartz Ti-center in ESR dating of fluvial sediment. Nucl. Technol. 2, 110–112.

Liu, Y., Feng, X.B., 2014. Handaxes of 100–50 ka B.P. found in Yunxian County, Hubei. In: Weekly of Chinese Cultural Relics, 3rd of January, 8 (in Chinese).

Lycett, S.J., Bae, C.J., 2010. The Movius Line controversy: the state of the debate. World Archaeol. 42 (4), 521–544.

Lycett, S.J., Norton, C.J., 2010. A demographic model for Palaeolithic technological evolution: the case of East Asia and the Movius Line. Quat. Int. 211, 55–65.

Lycett, S.J., 2007. Why is there a lack of Mode 3 Levallois technologies in East Asia? A phylogenetic test of the Movius-Schick hypothesis. J. Anthropol. Archaeol. 26, 541–575.

Lycett, S.J., 2008. Acheulean variation and selection: does handaxe symmetry fit neutral expectations? J. Archaeol. Sci. 35 (9), 2640–2648.

Lycett, S.J., von Cramon-Taubadel, N., 2008. Acheulean variability and hominin dispersals: a model-bound approach. J. Archaeol. Sci. 35 (3), 553–562.

Marshall, G.D., Gamble, C.G., Roe, D.A., Dupplaw, D., 2002. Acheulian Biface Database. Archaeology Data Service, York. Available at: http://ads.ahds.ac.uk/catalogue/specColl/bifaces/bf_query.cfm.

McPherron, S.P., 2003. Technological and typological variability in the bifaces from Tabun Cave, Israel. In: Soressi, M., Dibble, H.L. (Eds.), Multiple Approaches to the Study of Bifacial Technologies. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, pp. 55–75.

Niu, D.W., Ma, N., Pei, S.W., Peng, F., 2012. A preliminary report on the excavation of the Songwan Paleolithic locality in the Danjingkou Reservoir Region. Acta Anthropol. Sin. 31 (1), 11–23 (in Chinese, with English abstract).

Niu, D.W., Pei, S.W., Yi, M.J., Ma, N., 2014. The lithic assemblage from the Jiawan Paleolithic locality 1 in the Danjingkou Reservoir Region. Acta Anthropol. Sin. 33 (2), 149–161 (in Chinese, with English abstract).

Norton, C.J., Bae, K., 2008. The Movius Line sensu lato (Norton et al., 2006) further assessed and defined. J. Hum. Evol. 55, 1148–1150.

Norton, C.J., Bae, K., Harris, J.W.K., Lee, H., 2006. Middle Pleistocene handaxes from the Korean Peninsula. J. Hum. Evol. 51, 527–536.

Pei, S.W., Guan, Y., Gao, X., 2008. A preliminary report on the excavation of the Pengjiahe Paleolithic site in the Danjiangkou Reservoir Region. Acta Anthropol. Sin. 27 (2), 95–110 (in Chinese, with English abstract).

Petraglia, M.D., Shipton, C., 2008. Large cutting tool variability west and east of the Movius Line. J. Hum. Evol. 55, 962–966.

Pope, M.I., 2002. The Significance of Biface-rich Assemblages: an Examination of Behavioural Controls on Lithic Assemblage Formation in the Lower Palaeolithic (Unpublished Ph.D. thesis). University of Southampton, Southampton.

Qiu, Z.L., Xu, C.H., Zhang, W.H., Wang, R.L., Wang, J.Z., Zhao, C.F., 1982. A human fossil tooth and fossil mammals from Nanzhao, Henan. Acta Anthropol. Sin. 1 (2), 109–117 (in Chinese, with English abstract).

Rink, W.J., Bartoll, J., Schwarcz, H.P., Shane, P., Bar-Yosef, O., 2007. Testing the reliability of ESR dating of optically exposed buried quartz sediments. Radiat. Meas. 42, 1618–1626.

Schick, K., 1986. Stone Age Sites in the Making: Experiments in the Formation and Transformation of Archaeological Occurrences. In: British Archaeological Reports International Series, vol. 319 (Oxford).

Schick, K., 1997. Experimental studies of site-formation processes. In: Isaac, G.L. (Ed.), Koobi Fora Research Project, Plio-Pleistocene Archaeology, vol. 5. Clarendon Press, Oxford, pp. 244–261.

Schick, K., Clark, J.D., 2003. Biface technological development and variability in the Acheulean industrial complex in the Middle Awash Region of the Afar Rift, Ethiopia. In: Soressi, M., Dibble, H.L. (Eds.), Multiple Approaches to the Study of Bifacial Technologies. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, pp. 1–30.

Schick, K., Toth, N., 2006. An overview of the Oldowan industrial complex: the sites and the nature of their evidence. In: Toth, N., Schick, K. (Eds.), The Oldowan: Case Studies into the Earliest Stone Age. Stone Age Institute Press, Gosport, pp. 3–42.

Semaw, S., Rogers, M., Stout, D., 2009. The Oldowan-Acheulian transition: is there a "Developed Oldowan" artifact tradition? In: Camps, M., Chauhan, P.R. (Eds.), Sourcebook of Paleolithic Transitions. Springer, New York, pp. 173–192.

Sharon, G., 2007. Acheulian Large Flake Industries: Technology, Chronology, and Significance. In: British Archaeological Reports International Series, vol. 1701. Oxford.

Sharon, G., Alperson-Afil, N., Goren-Inbar, N., 2011. Cultural conservatism and variability in the Acheulian sequence of Gesher Benot Ya'aqov. J. Hum. Evol. 60, 387–397.

Shen, Y.C., 1956. Landscape and its development history of Hanjiang River Valley. Acta Geogr. Sin. 22 (4), 295–321 (in Chinese, with English abstract).

Shipton, C., Petraglia, M.D., 2010. Inter-continental variation in Acheulean bifaces. In: Norton, C.J., Braun, D.R. (Eds.), Asian Paleoanthropology: From Africa to China and Beyond. Springer Press, pp. 49–55.

Sussman, C., 1985. Microwear on quartz tools: fact or fiction? World Archaeol. 17 (1), 101–111.

Sussman, C., 1988. A Microscopic Analysis of Use-wear and Polish Formation on Experimental Quartz Tools. In: British Archaeological Reports International Series, vol. 395. Oxford.

Szabo, B.J., McKinney, C., Dalbey, T.S., Paddayya, K., 1990. On the age of the Acheulian culture of the Hunsgi-Baichbal Valleys, Peninsular India. Bull. Deccan Coll. Postgrad. Res. Inst. 50, 317–321.

Tissoux, H., Falguères, C., Voinchet, P., Toyoda, S., Bahain, J.J., Despriée, J., 2007. Potential use of Ti-center in ESR dating of fluvial sediment. Quat. Geochronol. 2, 367–372.

Toth, N., 1982. The Stone Technologies of Early Hominids at Koobi Fora, Kenya: an Experimental Approach (Unpublished Ph.D. thesis). University of California, Berkeley.

Toth, N., 1985. The Oldowan ressessed: a close look at early stone artifacts. J. Archaeol. Sci. 12, 101–120.

Tryon, C.A., Potts, R., 2011. Special issue: reduction sequence, Chaîne Opératoire, and other methods: the Epistemologies of different approaches to lithic analysisApproaches for understanding flake production in the African acheulean. PaleoAnthropology 376–389.

Voinchet, P., Despriée, J., Tissoux, H., Falguères, C., Bahain, J.J., Gageonnet, R., Dépont, J., Dolo, J.M., 2010. ESR chronology of alluvial deposits and first human settlements of the Middle Loire Basin (Region Centre, France). Quat. Geochronol. 5, 381–384.

Wang, H.Q., Deng, C.L., Zhu, R.X., Wei, Q., Hou, Y.M., Boëda, E., 2005. Magnetostratigraphic dating of the Donggutuo and Maliang Paleolithic sites in the Nihewan basin, North China. Quat. Res. 64, 1–11.

Wang, S.J., 2005. Perspectives on Hominid Behaviour and Settlement Patterns: a Study of the Lower Palaeolithic Sites in the Luonan Basin, China. In: British Archaeological Reports International Series, vol. 1406. Oxford.

Wang, S.J., 2007. Huashilang (I): the Paleolithic Open-air Sites in the Luonan Basin, China. Science Press, Beijing (in Chinese, with English abstract).

Wang, S.J., Sun, X.F., Lu, H.Y., Yi, S.W., Zhang, G.K., Xing, L.D., Zhuo, H.X., Yu, K.F., Wang, W., 2014a. Newly discovered Paleolithic open-air sites in Hanzhong Basin in upper valley of Hanjiang River and their ages. Acta Anthropol. Sin. 33 (2), 125–136 (in Chinese, with English abstract).

Wang, S.J., Zhang, X.B., Lu, H.Y., Xing, L.D., Zhang, G.K., 2013. New discovered Paleolithic open-air sites at Shangdan Basin in the upper Danjiang River valley, eastern Qinling Mountains, central China. Acta Anthropol. Sin. 32 (4), 421–431 (in Chinese, with English abstract).

Wang, W., Bae, C.J., Huang, S., Huang, X., Tian, F., Mo, J., Huang, Z., Huang, C., Xie, S., Li, D., 2014b. Middle Pleistocene bifaces from Fengshudao (Bose Basin, Guangxi, China). J. Hum. Evol. 69, 110–122.

Wang, W., Lycett, S.J., Cramon-Taubadel, N., Jin, J.J.H., Bae, C.J., 2012. Comparison of handaxes from Bose Basin (China) and the western Acheulean indicates convergence of form, not cognitive differences. PLoS ONE 7 (4), 1–7.

Wang, W., Mo, J.Y., Huang, Z.T., 2008. Recent discovery of handaxes associated with tektites in the Nanbanshan locality of the Damei site, Bose basin, Guangxi, South China. Chin. Sci. Bull. 53, 878–883.

Wang, Y.P., 1988. Xiaokongshanshangdong cave in Nanzhao and Zhangnaodong cave in Fangxian – comparison of two Late Paleolithic cave sites in the Han River valley. Huaxia Archaeol. 4, 38–42 (in Chinese).

White, M.J., 1998. On the significance of Acheulean biface variability in Southern Britain. Proc. Prehist. Soc. 64, 15–44.

Wu, X.Z., Liu, W., Gao, X., Yin, G.M., 2006. Late Pleistocene paleoanthropological site of Huanglong cave in Yunxi County, Hubei. Chin. Sci. Bull. 51 (16), 1929–1935 (in Chinese).

Wu, X.Z., Pei, S.W., Wu, X.J., Qu, S.M., Chen, M.H., Hu, Q., Liu, W., 2009. A preliminary study of the Bailong Cave Paleoanthropological site in Yunxi County, Hubei Province. Acta Anthropol. Sin. 28 (1), 1–15 (in Chinese, with English abstract).

Wu, X.Z., Wu, X.J., Chen, M.H., Qu, S.M., Pei, S.W., Liu, W., 2007. The 2006 excavation of Huanglong Cave in Yunxi County, Hubei. Acta Anthropol. Sin. 26 (3), 193–205 (in Chinese, with English abstract).

Wu, X.Z., Zhou, X.M., Wang, Y.F., 2008. A preliminary report of the Paleolithic site of Fulongguan from Yunxian, Hubei. Acta Anthropol. Sin. 27 (1), 33–37 (in Chinese, with English abstract).

Wynn, T., Tierson, F., 1990. Regional comparisons of the shapes of later Acheulean handaxes. Am. Anthropol. 92, 73–84.

Xue, X.X., Zhang, Y.X., Bi, Y., Yue, L.P., Chen, D.L., 1996. The Development and Environmental Changes of the Intermontane Basins in the Eastern Part of Qinling Mountains. Geological Publishing House, Beijing, pp. 1–66 (in Chinese, with English abstract).

Yan, G.L., 1993. A preliminary study on magnetic stratigraphy of the geological section with the fossil bed of Yunxian Homo of Hubei. Earth Sci.-J. China Univ. Geosci. 18 (2), 221–226 (in Chinese, with English abstract).

Yang, H., Zhao, Q.G., Li, X.P., Xia, Y.F., 1996. ESR dating of eolian sediment and red earth series from Xuancheng profile in Anhui Province. Acta Pedol. Sin. 33 (3), 293–300 (in Chinese, with English abstract).

Yin, Q.Z., Guo, Z.T., 2006. Mid-Pleistocene vermiculated red soils in Southern China and the unusually strengthened monsoon in East Asia. Chin. Sci. Bull. 51 (2), 186–193 (in Chinese).

Yuan, B., Xia, Z., Li, B., Qiao, Y., Gu, Z., Zhang, J., Xu, B., Huang, W., Zeng, R., 2008. Chronostratigraphy and stratigraphic division of red soil in Southern China. Quat. Sci. 28 (1), 1–12 (in Chinese, with English Abstract).

Zhang, G.W., Mei, Z.C., Zhou, D.W., Sun, Y., Yu, Z.P., 1988. Composition and evolution of the Qinling orogenic belt. In: Zhang, G.W. (Ed.), Composition and Evolution of the Qinling Orogenic Belt. Northwest University Press, Xi'an, pp. 1–16 (in Chinese, with English abstract).

Zhao, J.B., Yue, Y.L., Du, J., 2004. The fifth paleosol in loess and its environmental significance at Luochuan of Shaanxi. J. Desert Res. (1), 30–34 (in Chinese, with English abstract).

Zhao, Q.G., Yang, H., 1995. A preliminary study on red earth and changes of Quaternary environment in South China. Quat. Sci. (2), 107–116 (in Chinese, with English abstract).

Zhou, Z.Y., Wang, C.X., Gao, X., 2009. A preliminary report on the excavation of the Beitaishanmiao Paleolithic site at Danjiangkou, South China. Acta Anthropol. Sin. 28 (3), 246–261 (in Chinese, with English abstract).

Zhu, Z.D., 1955. Valley landscape of Hanjiang river upstream between Danjiangkou to Baihe. Acta Geogr. Sin. 21 (3), 259–270 (in Chinese, with English abstract).